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Effects of increasing amounts of non-polar organic liquids in domestic waste leachate on the hydraulic conductivity of clay

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EFFECTS OF INCREASING AMOUNTS OF NON-POLAR ORGANIC LIQUIDS IN DOMESTIC WASTE LEACHATE ON THE HYDRAULIC CONDUCTIVITY OF CLAY LINERS IN SOUTHERN ONTARIO

R. A. C. PROJECT NO. 213 PL/364 G

VOLUME 2

Report prepared for Environment Ontario by:

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OCTOBER 1989

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APPENDIX A

EVAPORATION CURVES FOR VARIOUS LIQUIDS

The following evaporation curves were obtained by weighting the effluent collection bottles containing 3 grams of various permeants at different time intervals.

The curves shown in Figure A.1 correspond to open bottles and illustrate the high volatility of the organic liquids relative to water. Figure A.2 shows evaporation curves for cyclohexane (the most volatile liquid tested) in the effluent bottles under different venting conditions. The teflon tube tips were adopted for the design of the effluent collection bottles used in the hydraulic conductivity testing for this project.

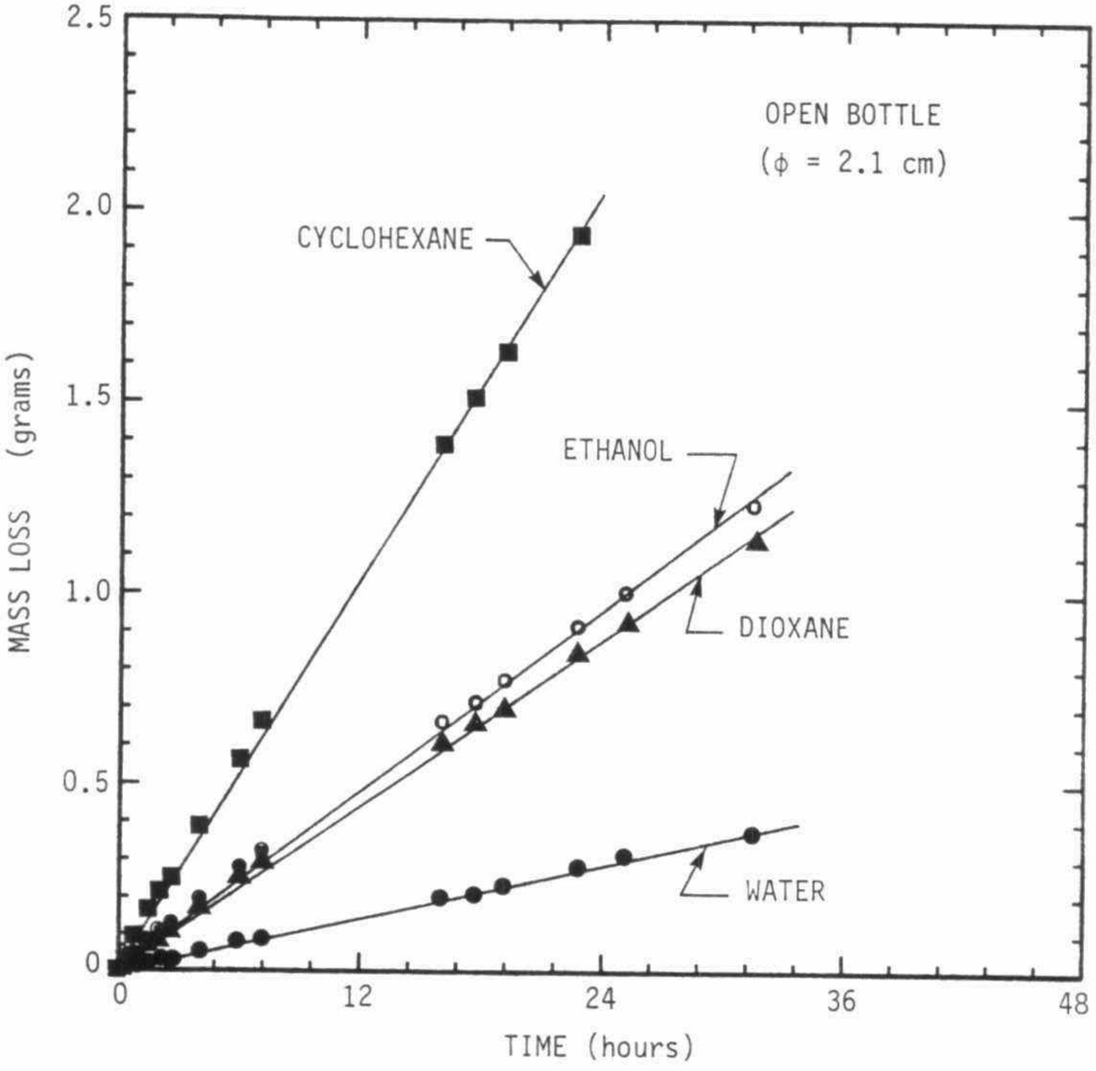

FIGURE A.1 EVAPORATION CURVES FOR VARIOUS LIQUIDS IN OPEN EFFLUENT COLLECTION BOTTLES

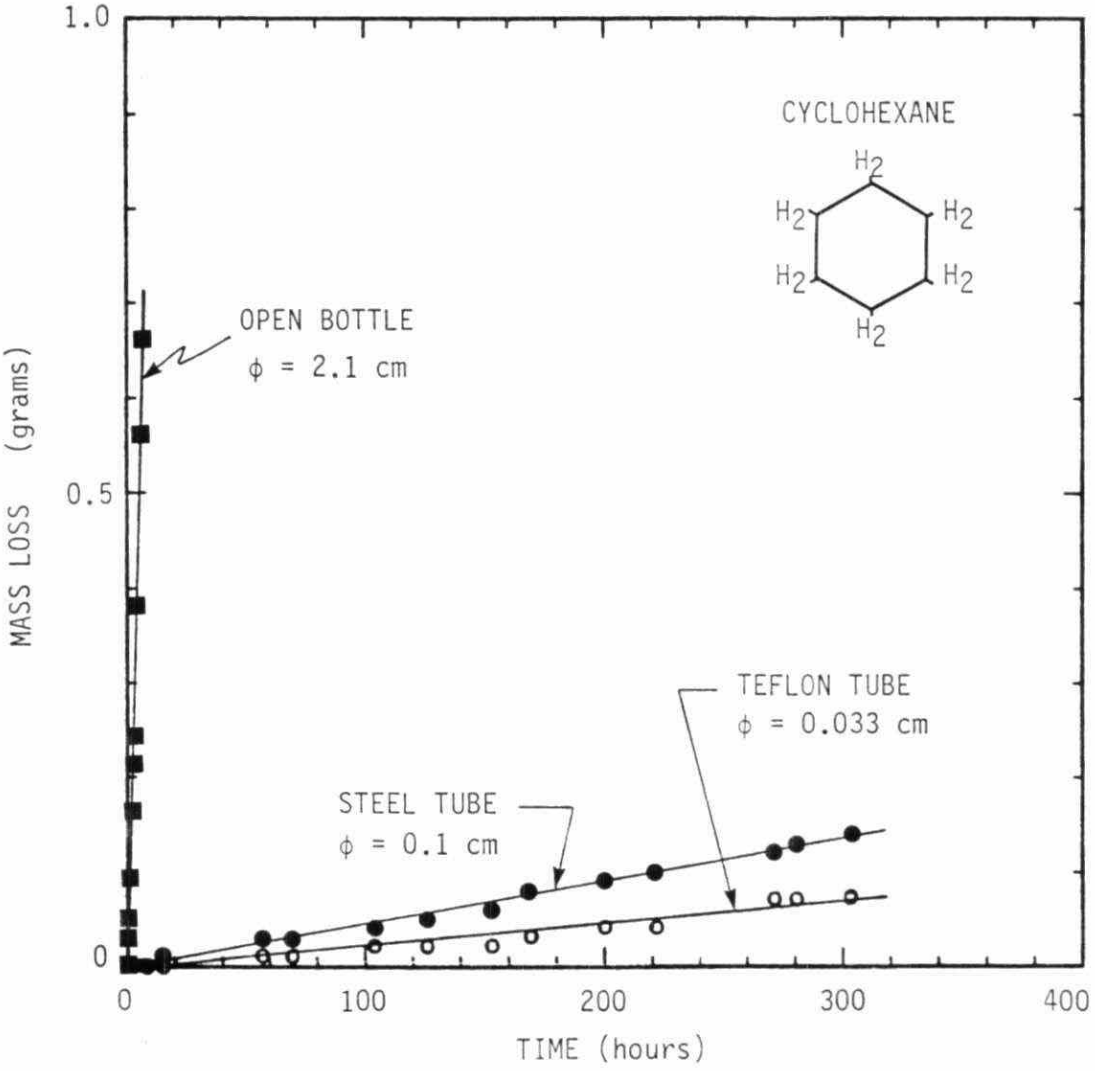

FIGURE A.2 EVAPORATION CURVES FOR CONCENTRATED CYCLOHEXANE IN EFFLUENT COLLECTION BOTTLES WITH DIFFERENT VENTING APERTURES, ϕ

APPENDIX B

INTERCONVERSION FORMULAS FOR COMPOSITION OF LIQUID SOLUTIONS

In a system where n_A moles of solvent A are mixed with n_B moles of solvent B the composition of the mixture can be expressed as follows:

χ_A = mole fraction of component A:

$$n_A = \frac{n_A}{n_A + n_B} \qquad ; \quad \chi_B = 1 - \chi_A$$

$\hat{W}_A$ = mass fraction (weight fraction) of component A:

$$\hat{W}_A = \frac{m_A}{m_A + m_B} = \frac{n_A}{(n_A + n_B \times M_B/M_A)} \qquad ; \quad \hat{W}_B = 1 - \hat{W}_A$$

ϕ_A = volume fraction of component A:

$$\phi_A = \frac{v_A}{v_A + v_B} = \frac{n_A}{(n_A + n_B \times V_B/V_A)} \qquad ; \quad \phi_B = 1 - \phi_A$$

where: $m_{A,B}$ = mass of n_A moles of component A,B

$M_{A,B}$ = mass of 1 mole (molar mass) of component A,B

$v_{A,B}$ = volume of $n_{A,B}$ moles of component A,B

$V_{A,B}$ = volume of 1 mole (molar volume) of component A,B

NOTE:

$$\boxed{\begin{array}{lll} \hat{W} \times 100 & = \text{Mass \%} & = \text{\% by wt} \\ \phi \times 100 & = \text{Volume \%} & = \text{\% by vol} \\ \chi \times 100 & = \text{Mole \%} & \end{array}}$$

Neglecting the volume change on mixing the following interconversion formulas are derived:

a) Mass fraction to volume fraction: $\phi_A = \dfrac{V_A}{V_A + V_B} =$

$$= \frac{m_A/\rho_A}{m_A/\rho_A + m_B/\rho_B} = \frac{m_A}{m_A + m_B(\rho_A/\rho_B)} = \frac{\dfrac{m_A}{m_A + m_B}}{\dfrac{m_A}{m_A + m_B} + (1 - \dfrac{m_A}{m_A + m_B})\rho_A/\rho_B}$$

$$\boxed{\phi_A = \frac{\hat{W}_A}{\hat{W}_A + (1 - \hat{W}_A)\rho_A/\rho_B}}$$

b) Mass fraction to mole fraction: $\chi_A = \dfrac{n_A}{n_A + n_B} =$

$$= \frac{m_A/M_A}{m_A/M_A + m_B/M_B} = \frac{m_A}{m_A + m_B(M_A/M_B)} = \frac{\dfrac{m_A}{m_A + m_B}}{\dfrac{m_A}{m_A + m_B} + (1 - \dfrac{m_A}{m_A + m_B})M_A/M_B}$$

$$\boxed{\chi_A = \frac{\hat{W}_A}{\hat{W}_A + (1 - \hat{W}_A)M_A/M_B}}$$

c) Volume fraction to mass fraction: $\hat{W}_A = \dfrac{m_A}{m_A + m_B} =$

$$= \frac{V_A\ \rho_A}{V_A\ \rho_A + V_B\ \rho_B} = \frac{V_A}{V_A + V_B(\rho_B/\rho_A)} = \frac{\dfrac{V_A}{V_A + V_B}}{\dfrac{V_A}{V_A + V_B} + (1 - \dfrac{V_A}{V_A + V_B})\rho_B/\rho_A}$$

$$\boxed{\hat{W}_A = \frac{\phi_A}{\phi_A + (1 - \phi_A)\rho_B/\rho_A}}$$

d) Volume fraction to mole fraction: $\chi_A = \frac{n_A}{n_A + n_B} =$

$$= \frac{v_A/V_A}{v_A/V_A + v_B/V_B} = \frac{v_A}{v_A + v_B(V_A/V_B)} = \frac{\dfrac{v_A}{v_A + v_B}}{\dfrac{v_A}{v_A + v_B} + (1 - \dfrac{v_A}{v_A + v_B})V_A/V_B}$$

$$\boxed{\chi_A = \frac{\phi_A}{\phi_A + (1 - \phi_A)V_A/V_B}}$$

e) Mole fraction to mass fraction: $\hat{w}_A = \frac{m_A}{m_A + m_B} =$

$$= \frac{n_A\,M_A}{n_A\,M_A + n_B\,M_B} = \frac{n_A}{n_A + n_B(M_B/M_A)} = \frac{\dfrac{n_A}{n_A + n_B}}{\dfrac{n_A}{n_A + n_B} + (1 - \dfrac{n_A}{n_A + n_B})M_B/M_A}$$

$$\boxed{\hat{w}_A = \frac{\chi_A}{\chi_A + (1 - \chi_A)M_B/M_A}}$$

f) Mole fraction to volume fraction: $\phi_A = \dfrac{v_A}{v_A + v_B} =$

$$= \frac{n_A\, V_A}{n_A\, V_A + n_B\, V_B} = \frac{n_A}{n_A + n_B(V_B/V_A)} = \frac{\dfrac{n_A}{n_A + n_B}}{\dfrac{n_A}{n_A + n_B} + (1 - \dfrac{n_A}{n_A + n_B})V_B/V_A}$$

$$\boxed{\phi_A = \frac{\chi_A}{\chi_A + (1 - \chi_A)V_B/V_A}}$$

where $\rho_{A,B}$ is the density of component A,B

The values of molar mass, molar volume and density of pure water, methanol, ethanol, acetone and dioxane are listed in Table B.1 as they are required to apply the conversion formulas for a particular water/hydrocarbon mixture. For example the formula to convert mass fractions to mole fractions for a water/dioxane mixture becomes:

$$\chi_{DIOX} = \frac{\hat{W}_{DIOX}}{\hat{W}_{DIOX} + (1 - \hat{W}_{DIOX})(88.06/18.02)} = \frac{\hat{W}_{DIOX}}{4.887 - 3.887\, \hat{W}_{DIOX}}$$

TABLE B.1 MOLAR MASS, MOLAR VOLUME AND DENSITY OF LIQUIDS AT 20°C

LIQUID	MOLAR MASS (g)	MOLAR VOLUME (cm^3)	DENSITY (g/cm^3)
WATER	18.02	18.05	0.99820
METHANOL	32.03	40.48	0.79133
ETHANOL	46.05	58.34	0.78934
ACETONE	58.05	73.50	0.7898
DIOXANE	88.06	85.23	1.03326

APPENDIX C

MEASUREMENT OF DIELECTRIC CONSTANT OF LIQUID PERMEANTS

The dielectric constant, ϵ, of permeant liquids was calculated from the capacitance of a the capacitor shown at the right of Figure 4.8, filled with permeant. Capacitance measurements were done using a Wayne-Kerr Autobalance Precision Bridge, model B331, at a frequency of ~ 1.6 kH. The voltages ranging from 1.2 V for water to 36 V for air.

For a given permeant the capacitance, C, equals:

$$1)\qquad C = \frac{\epsilon_o \ \epsilon \ A}{d}$$

where, ϵ_o = Permittivity of free space = 8.8542 picofarad per metre (pF/m)

A = Cross sectional area of the capacitor plates (m^2)

d = separation between capacitor plates (m)

For air ϵ = 1:

$$2)\qquad C_{air} = \frac{\epsilon_o \ 1 \ A}{d}$$

From 1) and 2):

$$C - C_{air} = \frac{\epsilon_o \ A}{d} (\epsilon - 1)$$

Therefore:

$$\boxed{\epsilon = \frac{d}{\epsilon_o \; A} (C - C_{air}) + 1}$$

This formula was used to calculate the dielectric constants of permeants from the capacitance values shown in Table C.1.

TABLE C.1 CAPACITANCE AND DIELECTRIC CONSTANTS OF PERMEANTS

MATERIAL	CAPACITANCE (pF)	DIELECTRIC CONSTANT
PURE COMPOUNDS		
Air	1.33	1.00
Water	37.4	83.6
Ethanol	14.9	32.1
Methanol	17.3	37.5
Dioxane	1.87	2.26
Cyclohexane	1.78	2.03
WATER MIXTURES		
10% Ethanol	35.4	78.9
20% Ethanol	33.1	73.8
35% Ethanol	29.4	65.3
50% Ethanol	25.4	56.1
65% Ethanol	21.7	47.7
80% Ethanol	18.6	40.5
90% Ethanol	16.7	36.2
10% Dioxane	30.9	68.8
20% Dioxane	27.3	60.5
35% Dioxane	21.5	47.1
50% Dioxane	15.5	33.5
65% Dioxane	9.85	20.5
80% Dioxane	4.84	9.06
90% Dioxane	3.51	6.02

APPENDIX D

HYDRAULIC CONDUCTIVITY CURVES FOR PERMEANT/CLAY MIXTURES

The hydraulic conductivity curves presented in this appendix correspond to dry clay samples mixed with the indicated test permeants. These permeants include water/ethanol, leachate/ethanol, water/dioxane and leachate/dioxane mixtures. The test soils are brown Sarnia clay, commercial (Black Hills) bentonite, and kaolinite.

The test results are discussed in Section 5.2 of this report.

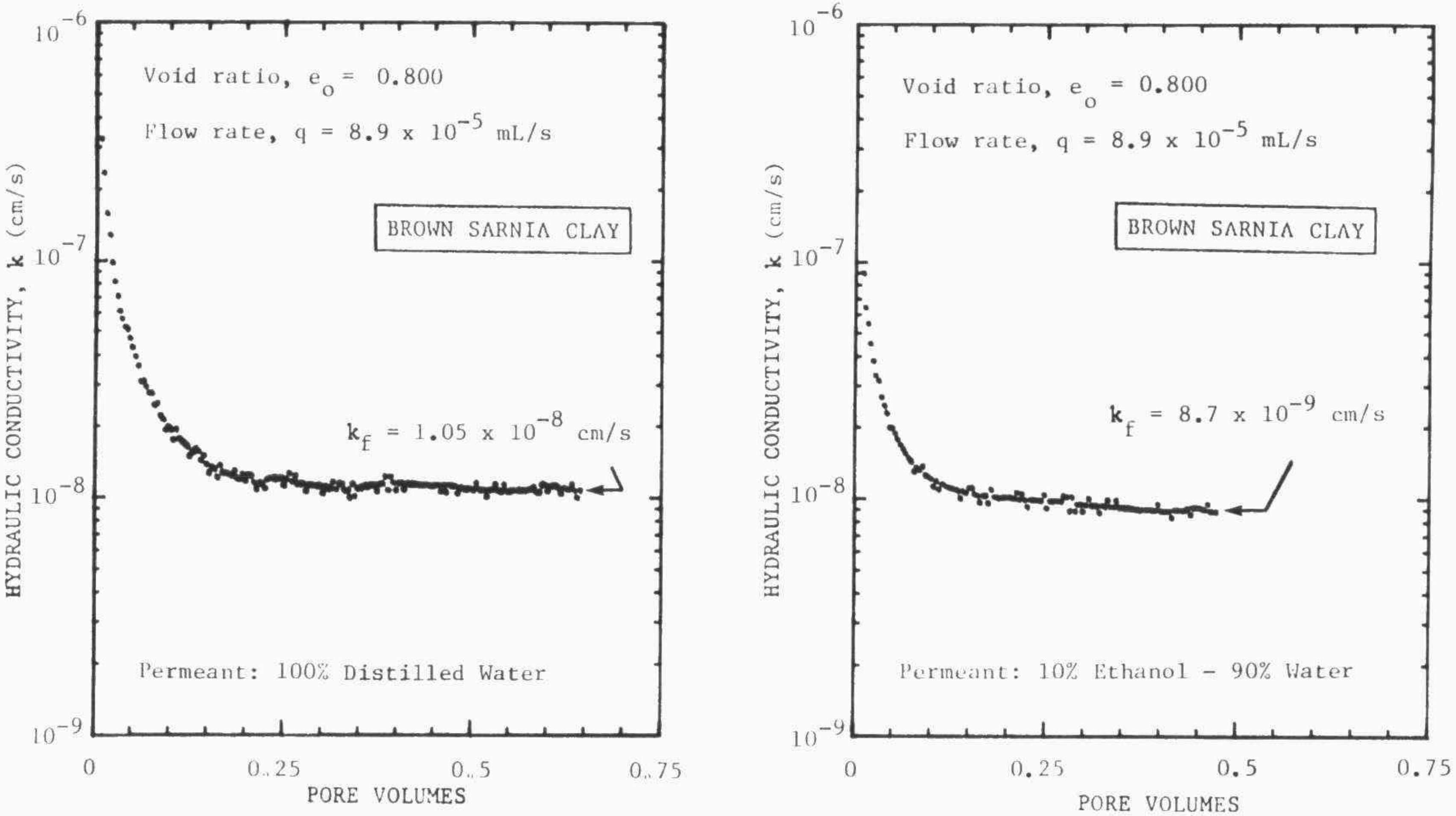

FIGURE D.1 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

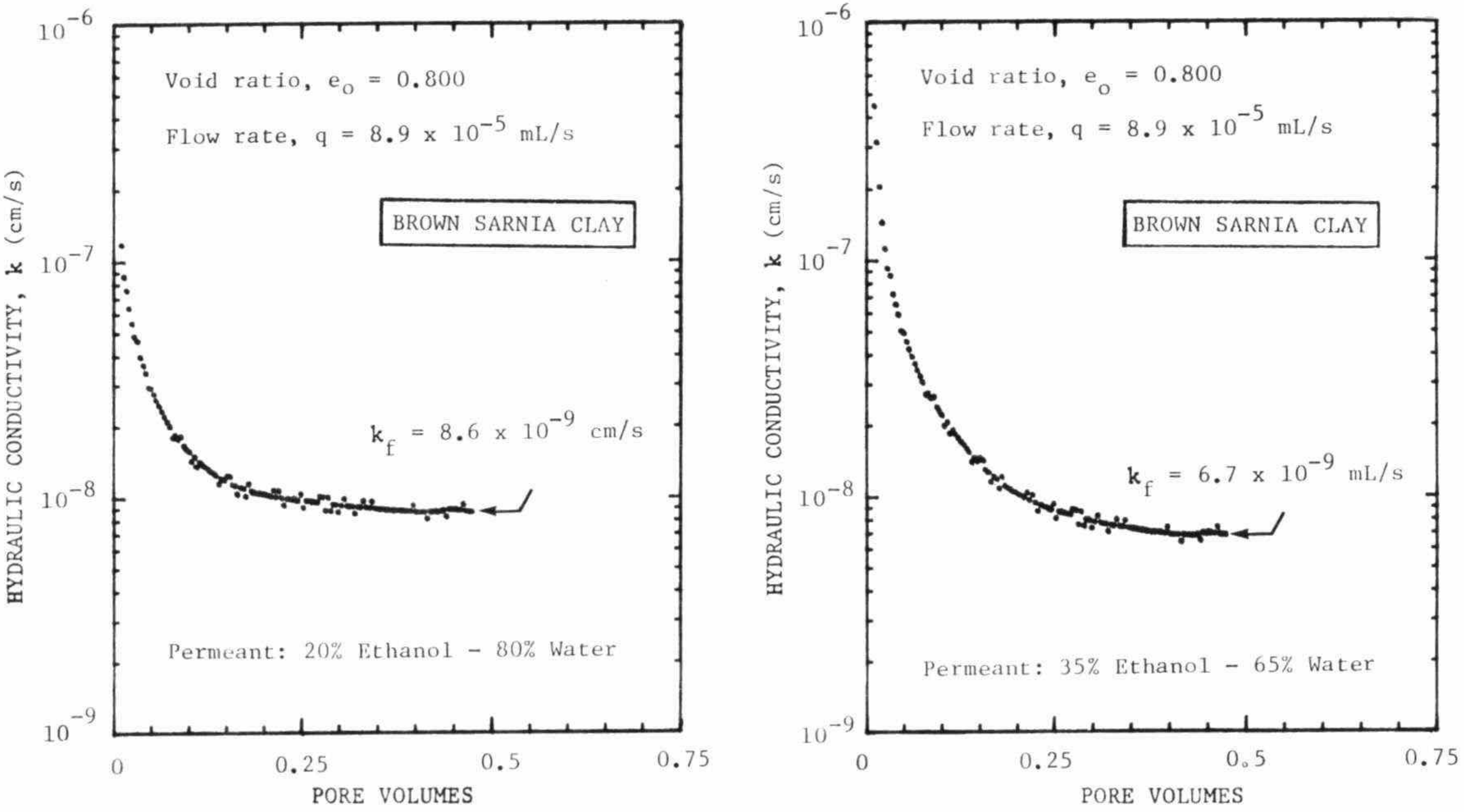

FIGURE D.2 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

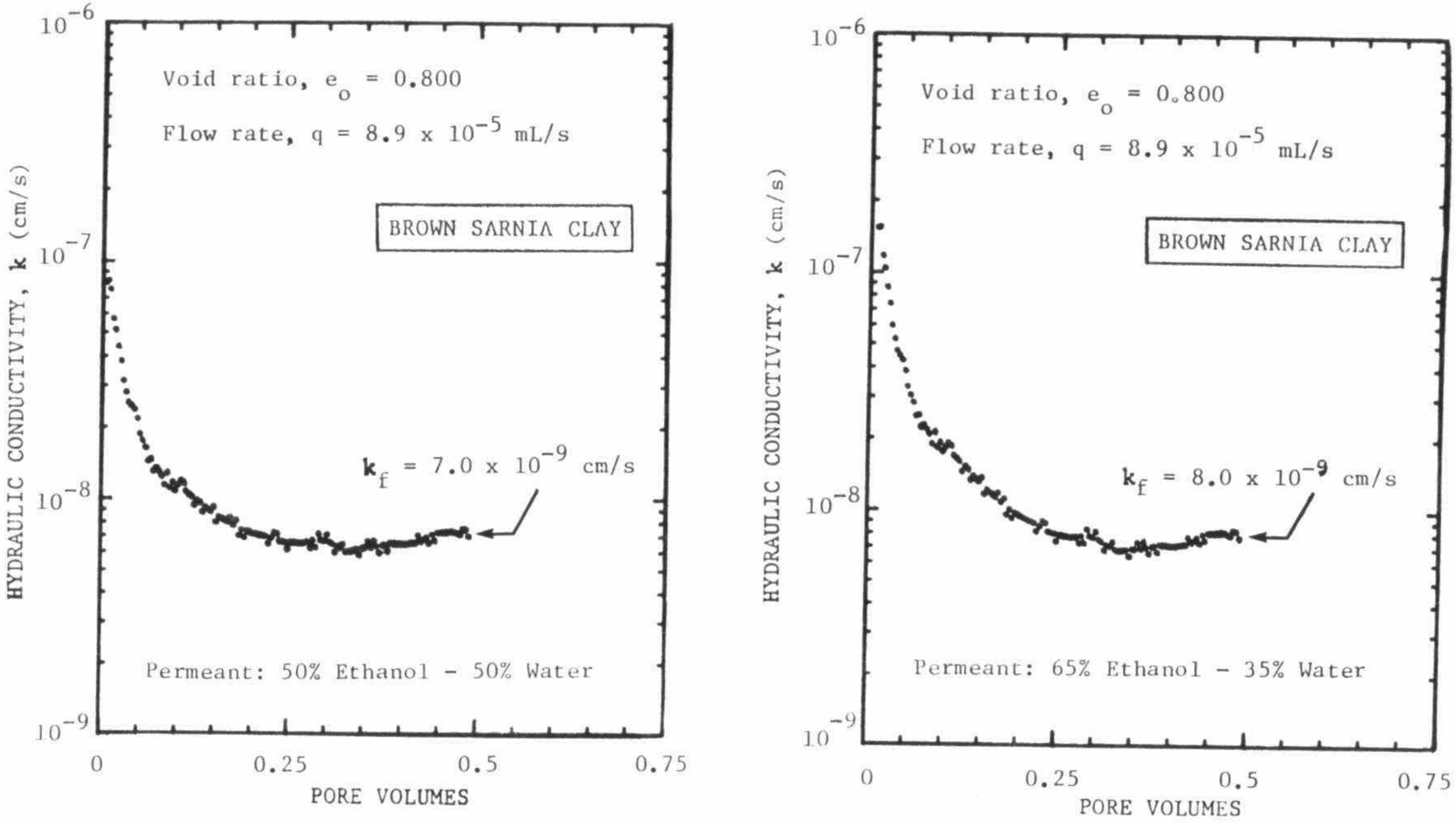

FIGURE D.3 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

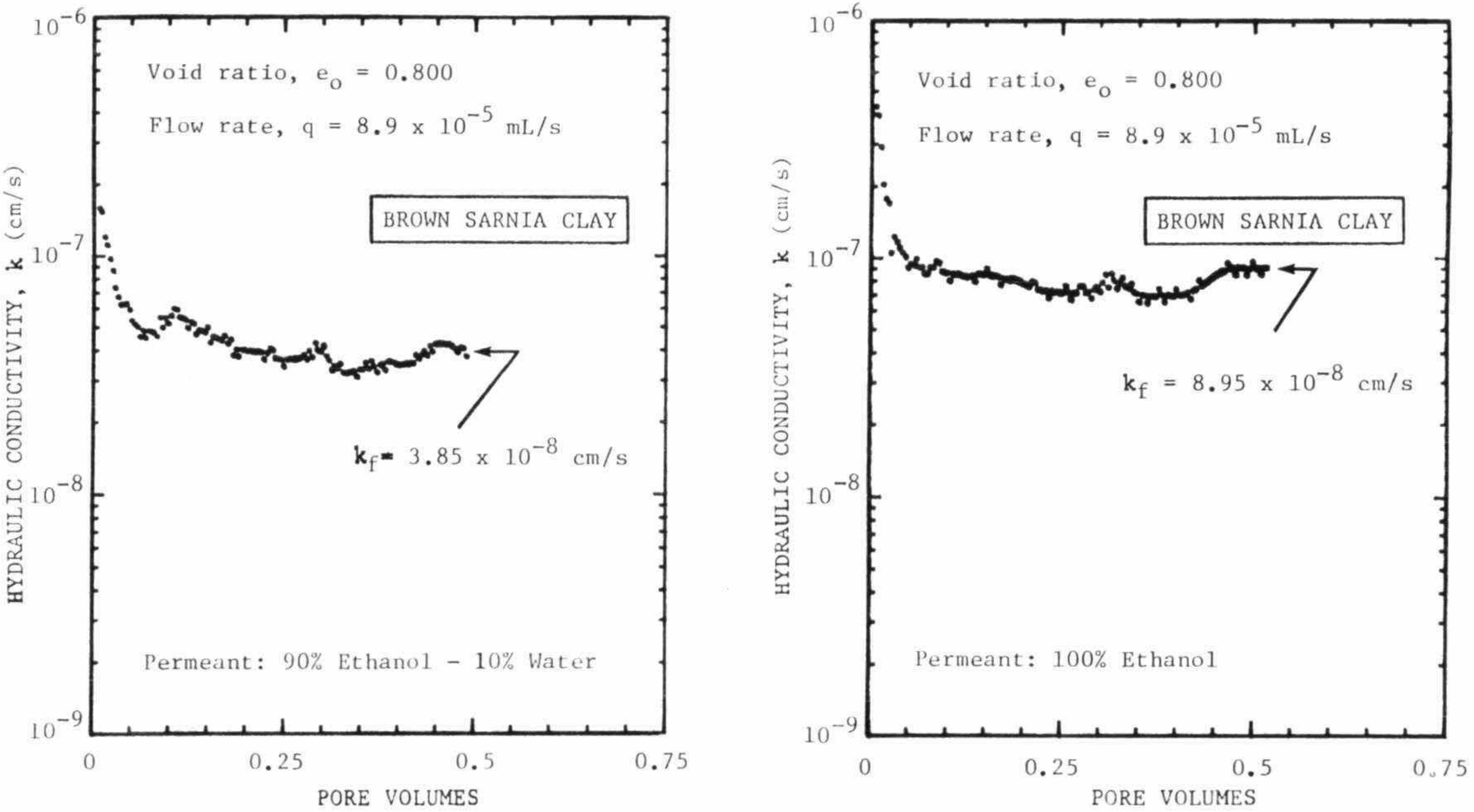

FIGURE D.4 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

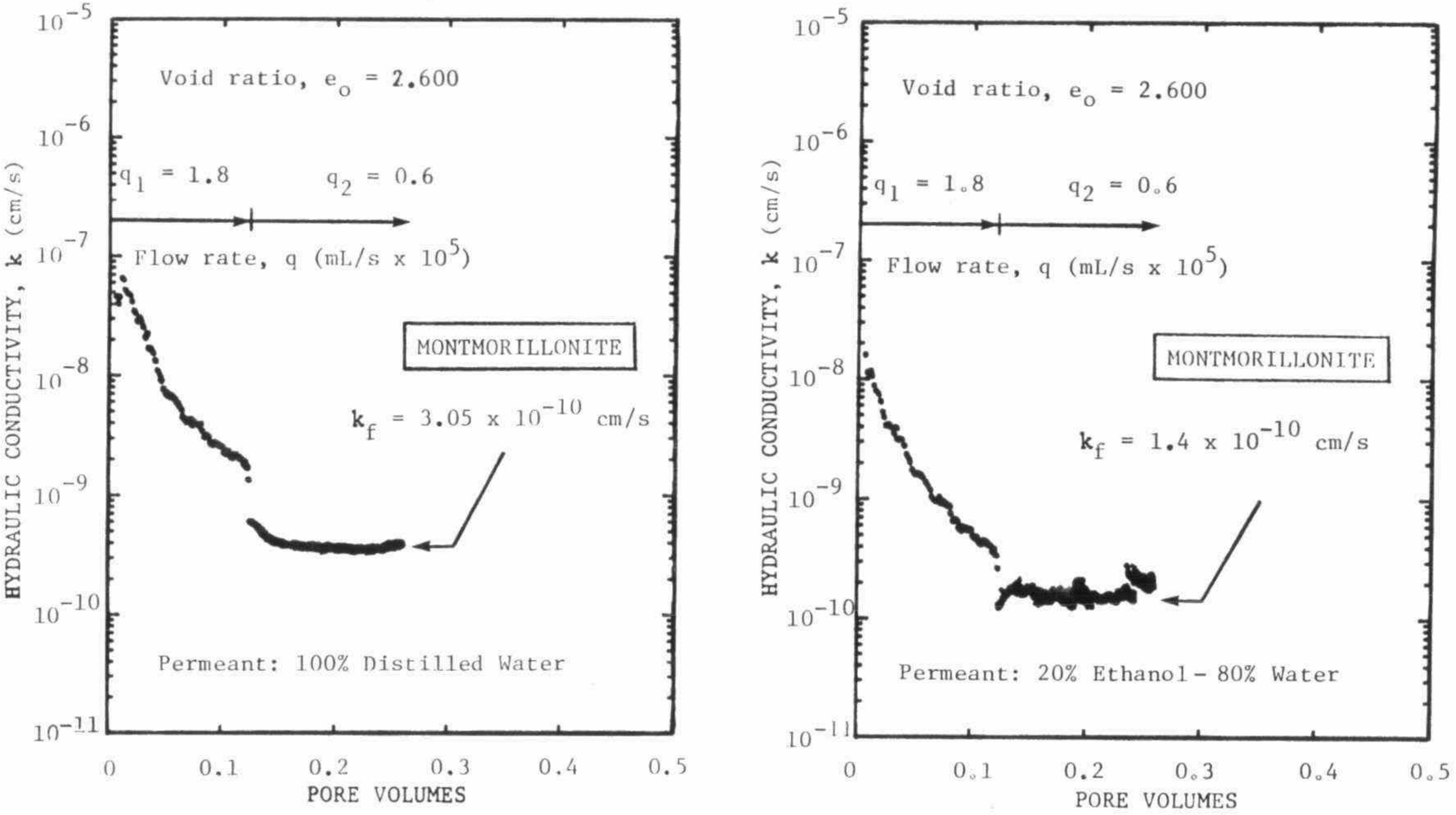

FIGURE D.5 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

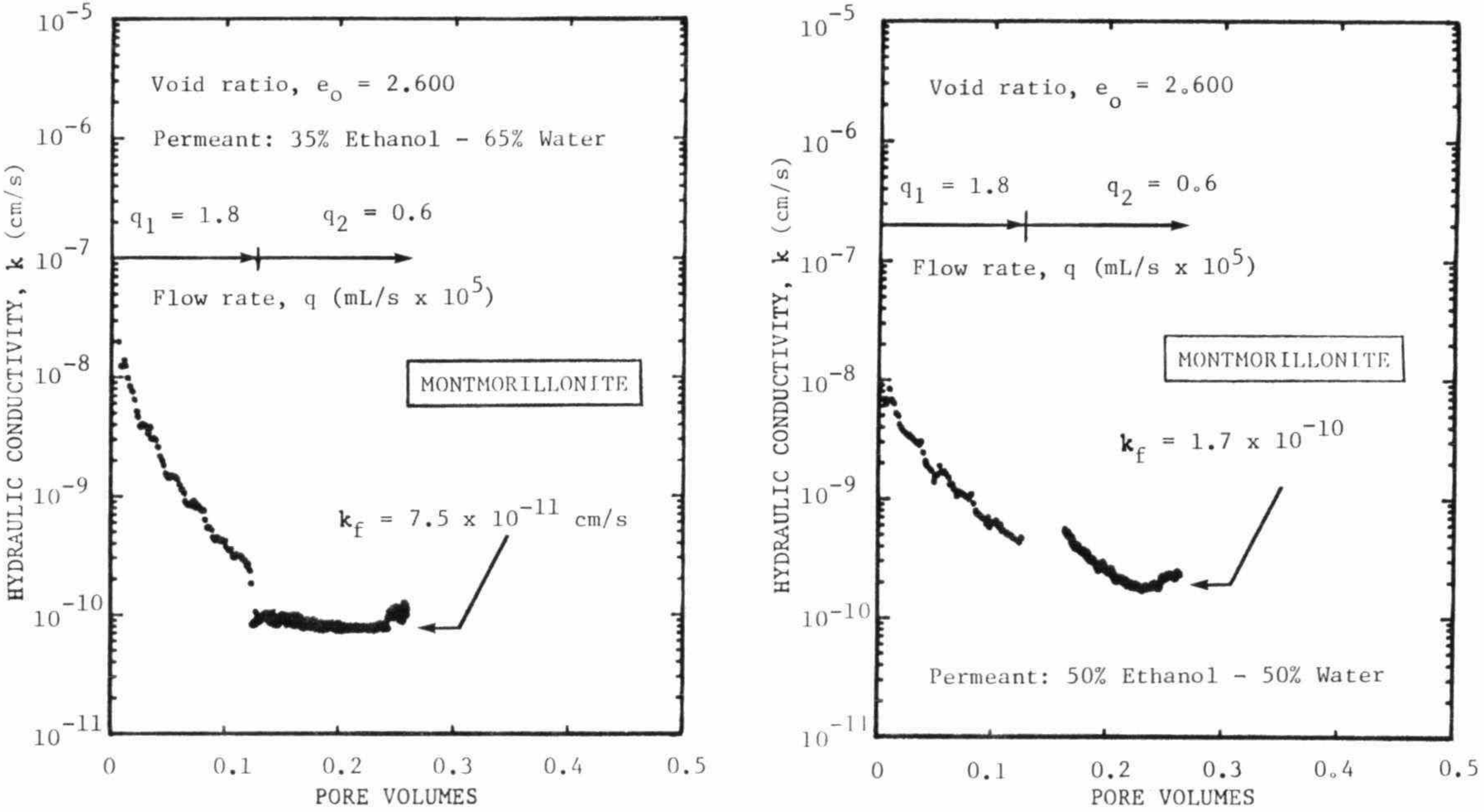

FIGURE D.6 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

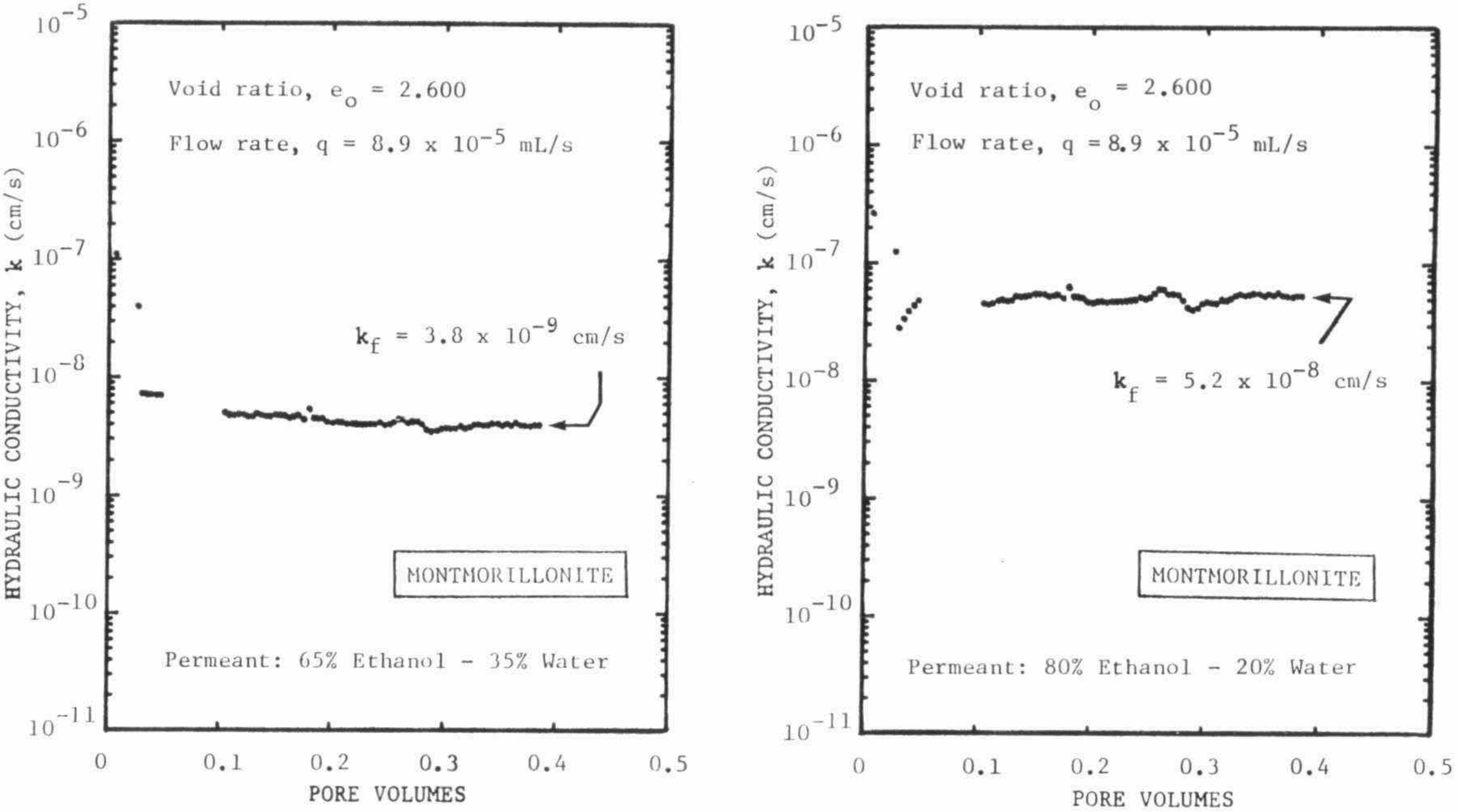

FIGURE D.7 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

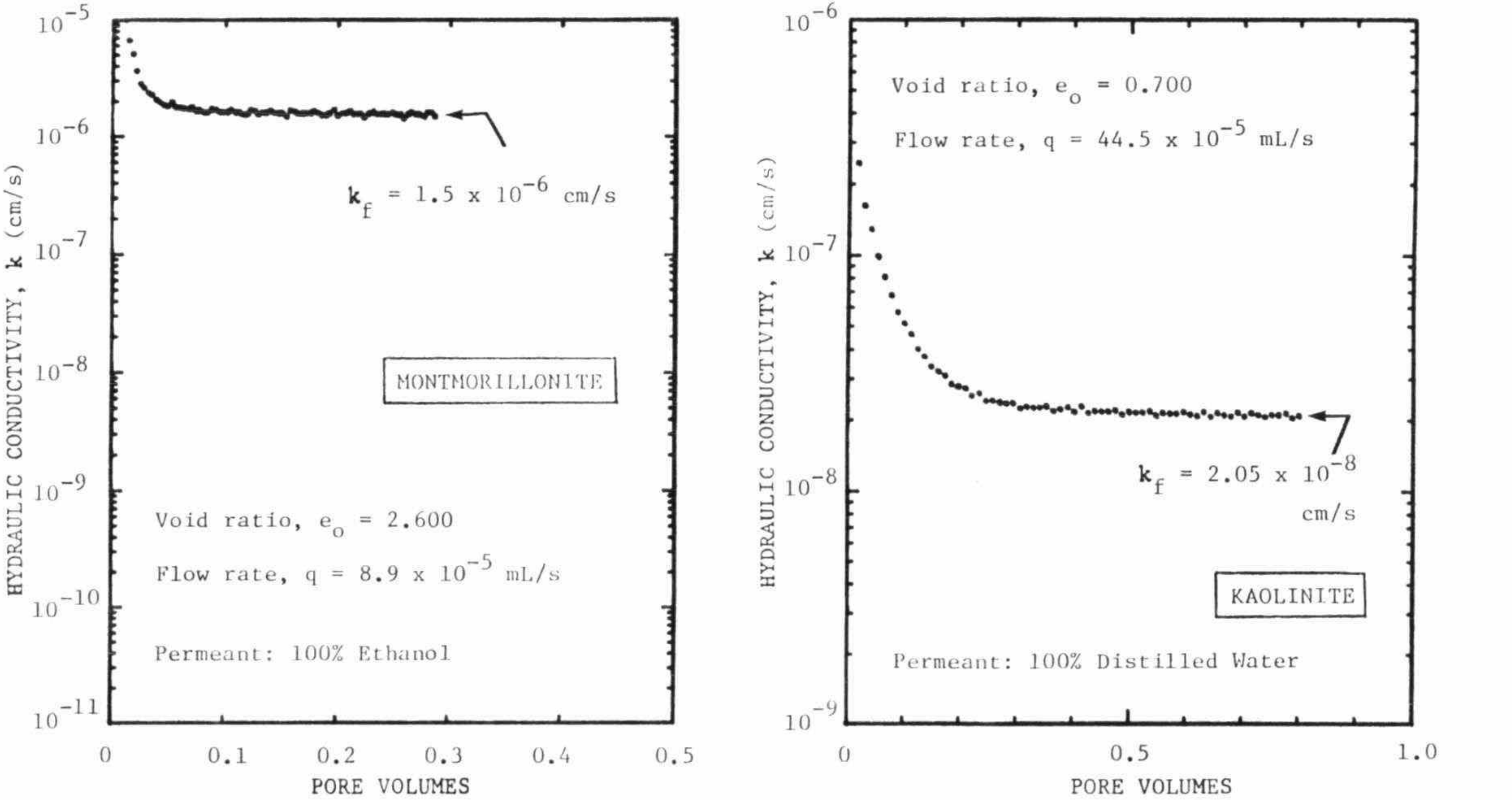

FIGURE D.8 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

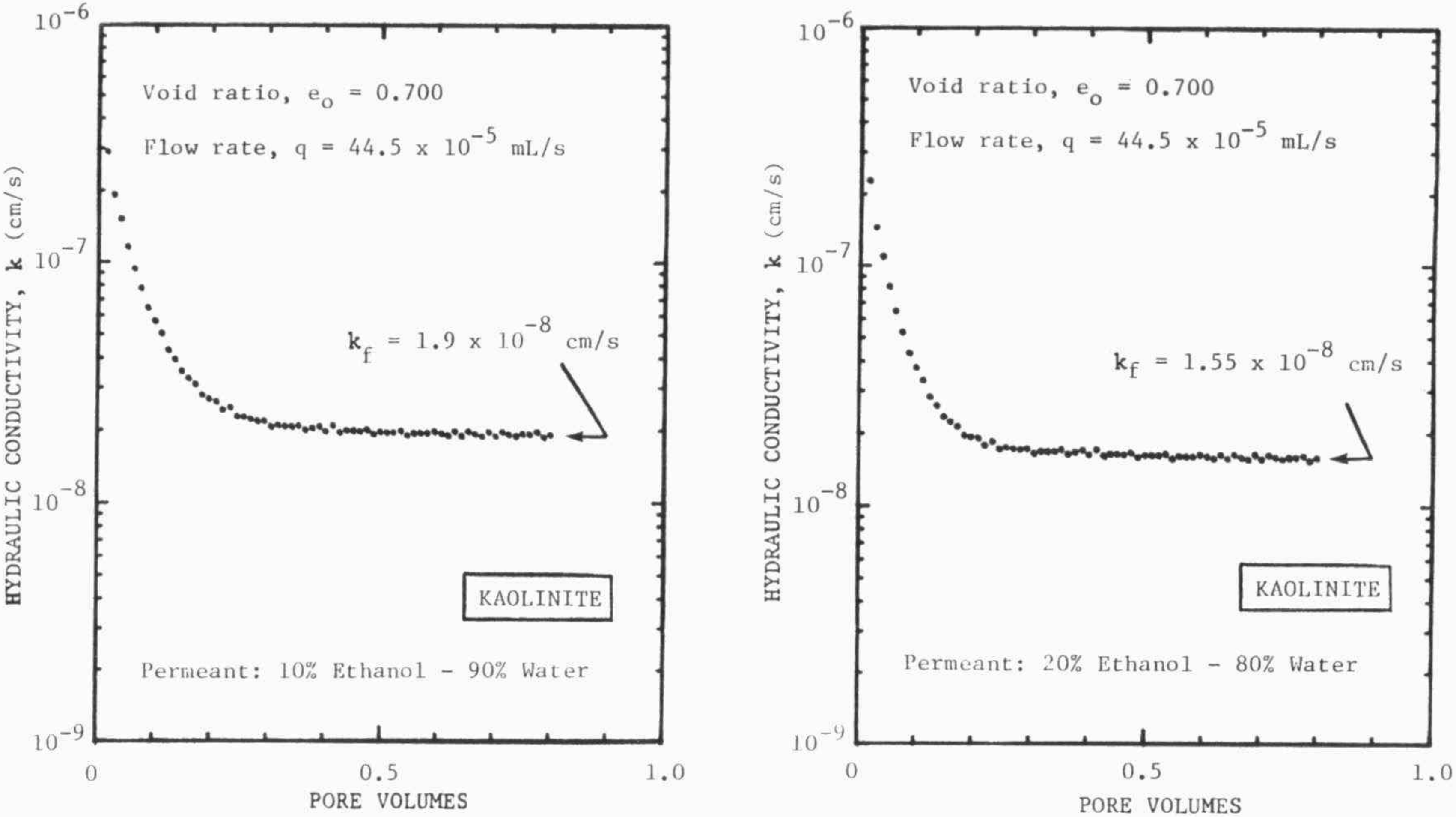

FIGURE D.9 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

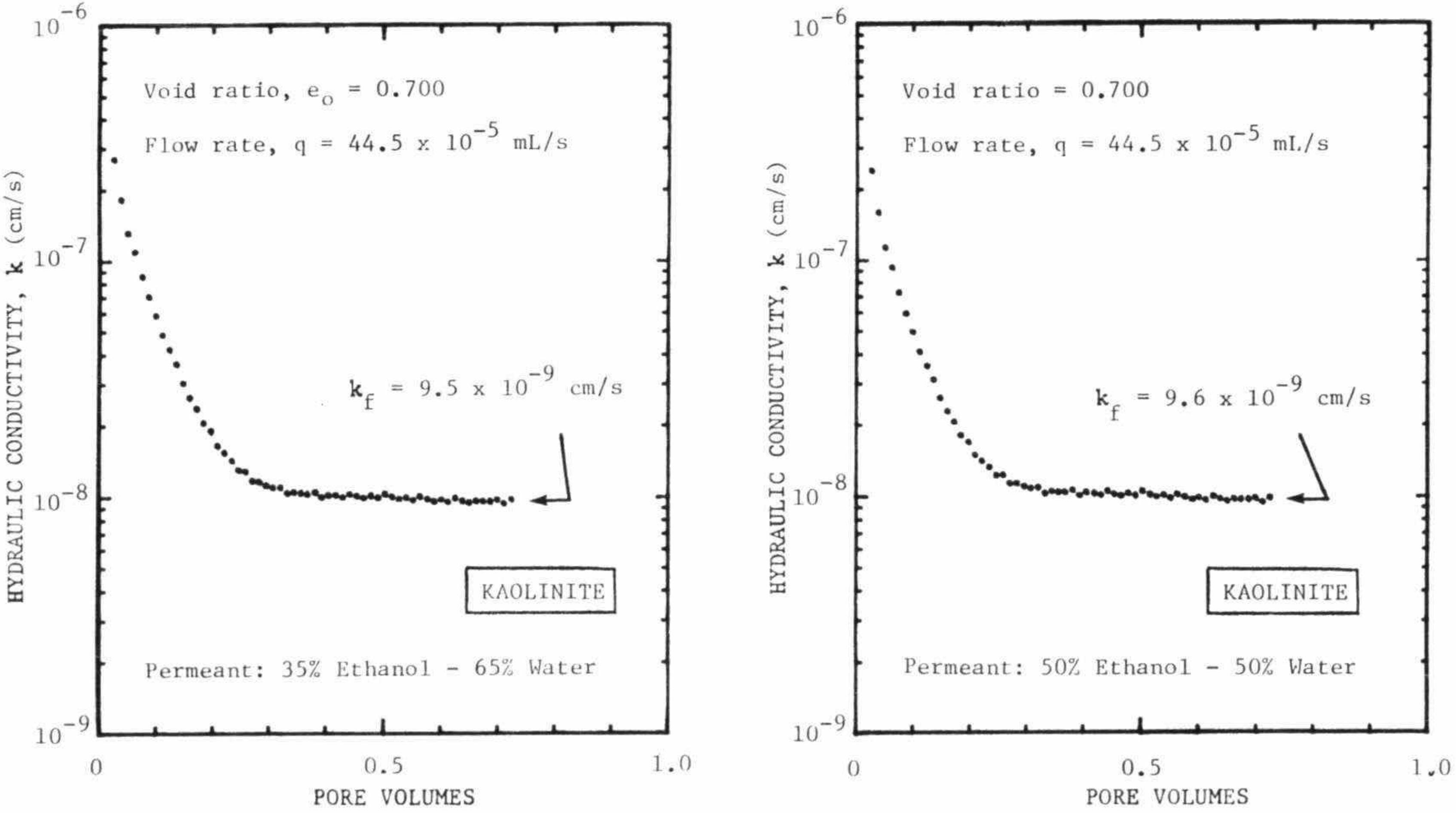

FIGURE D.10 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

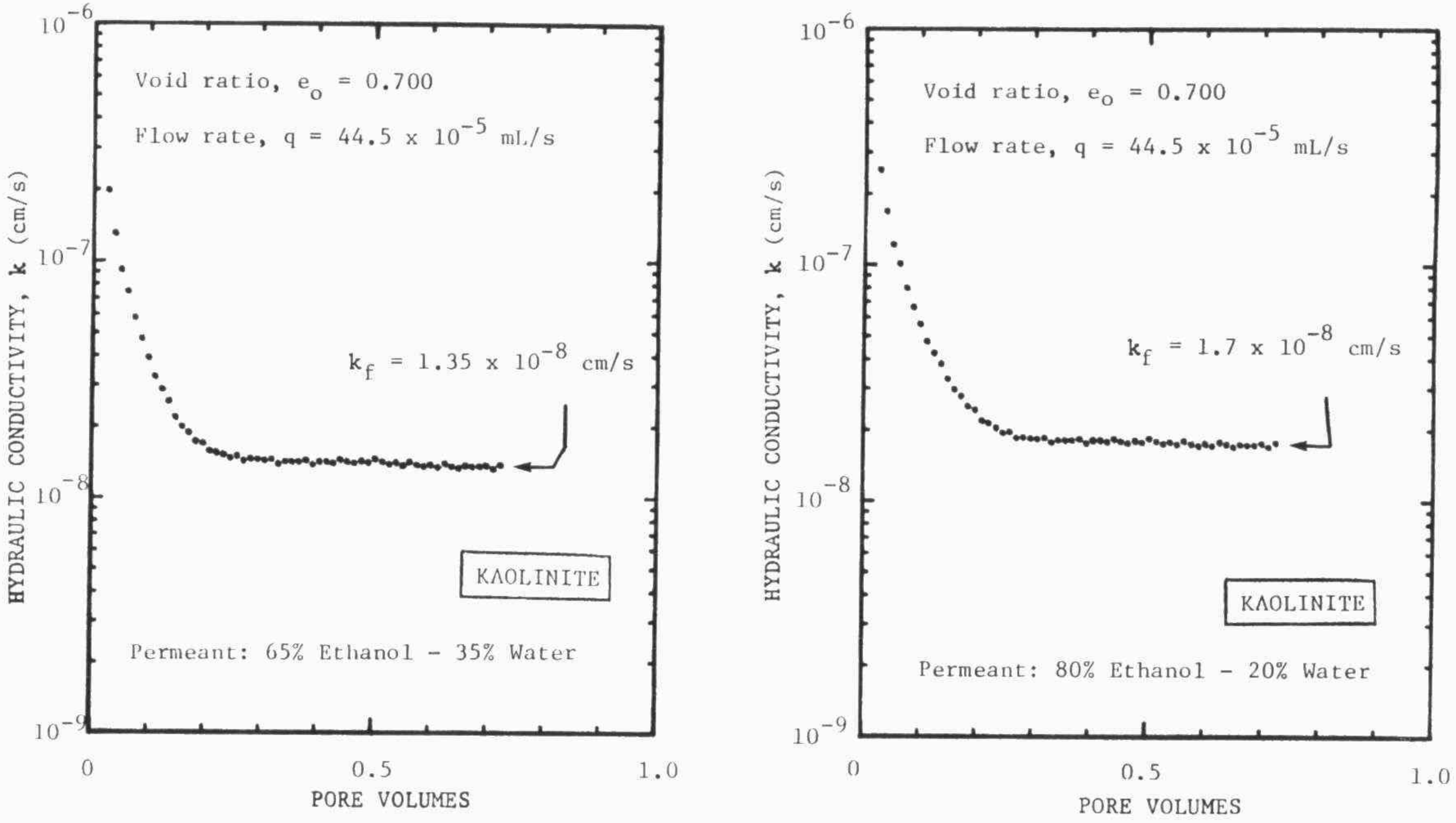

FIGURE D.11 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

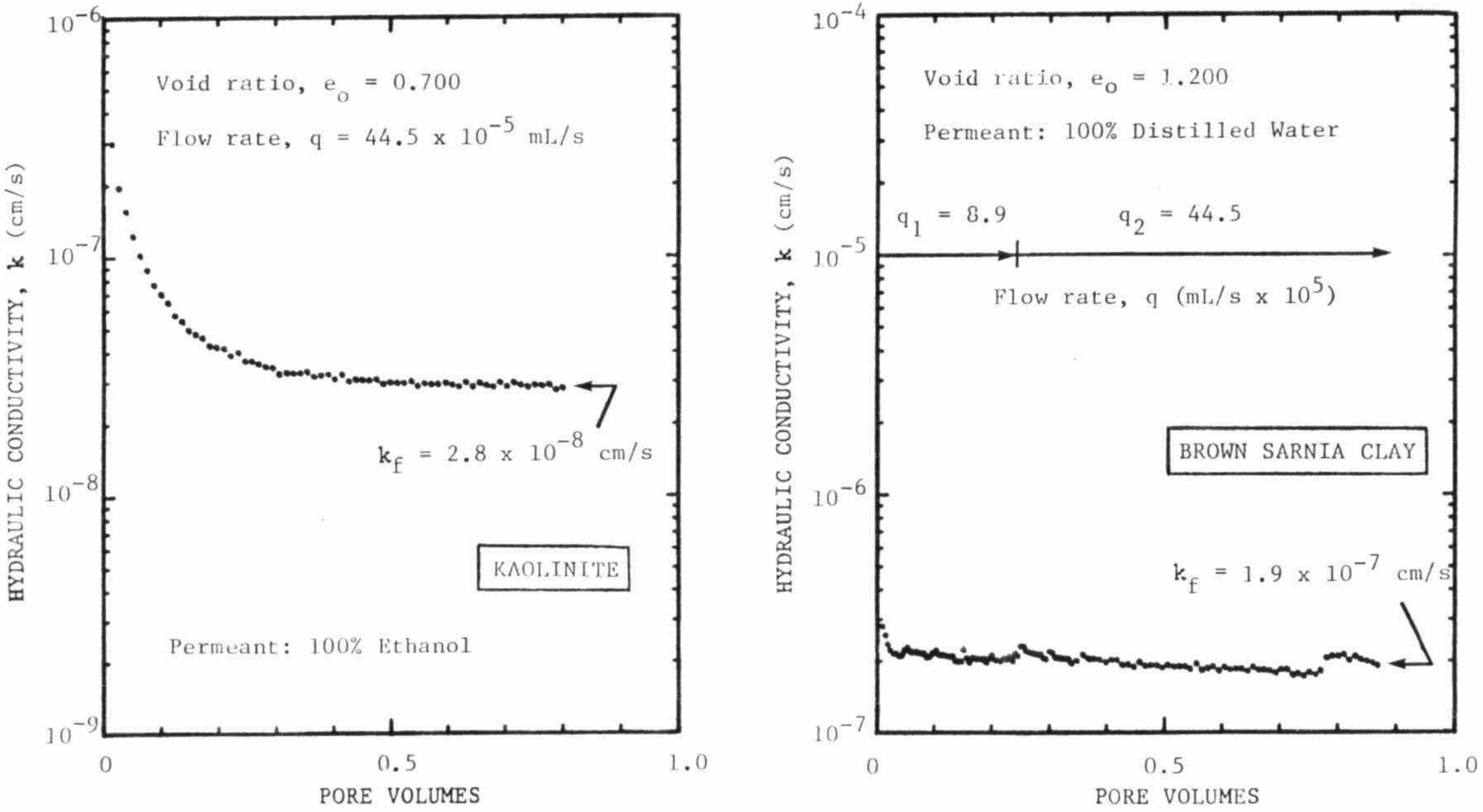

FIGURE D.12 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

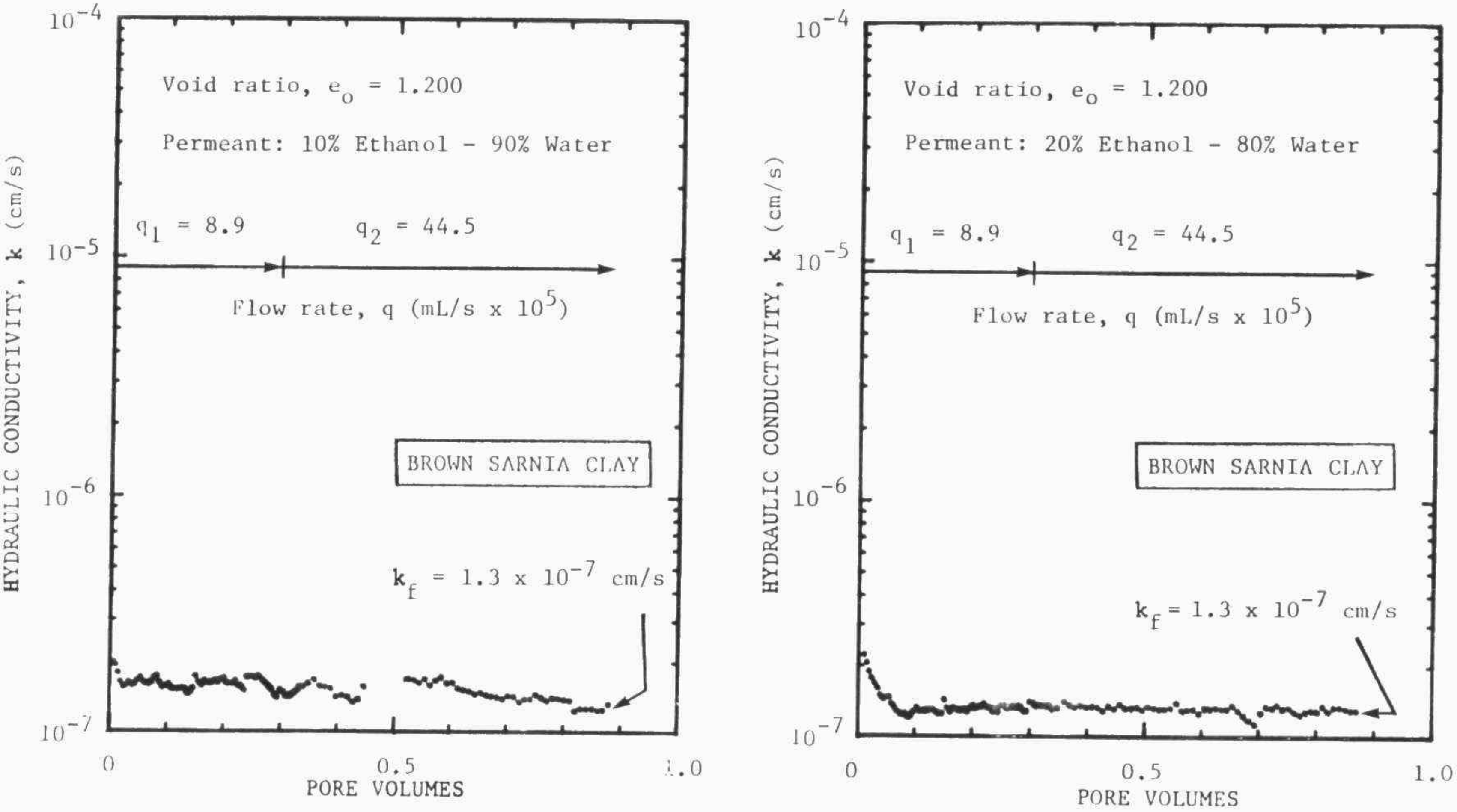

FIGURE D.13 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

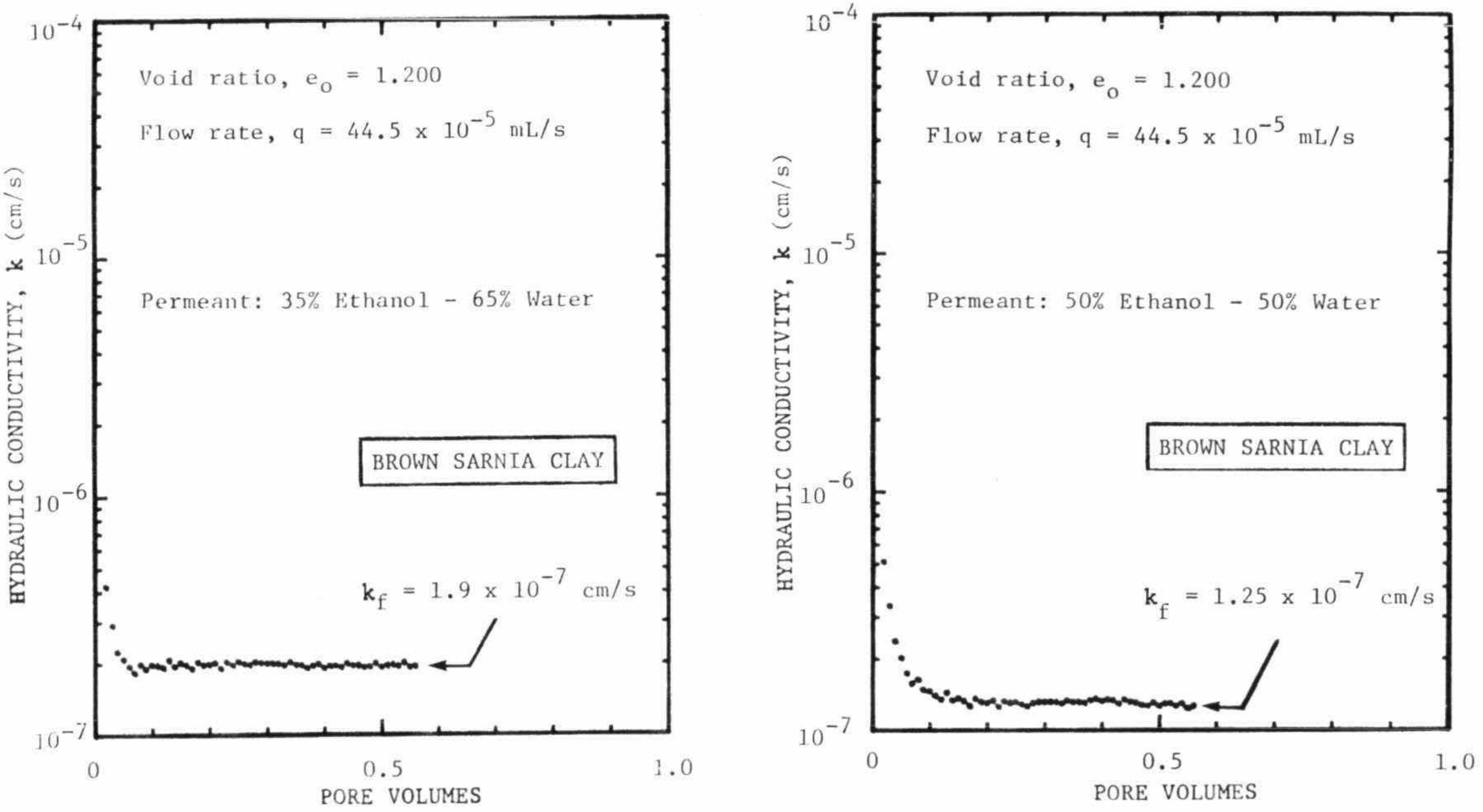

FIGURE D.14 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

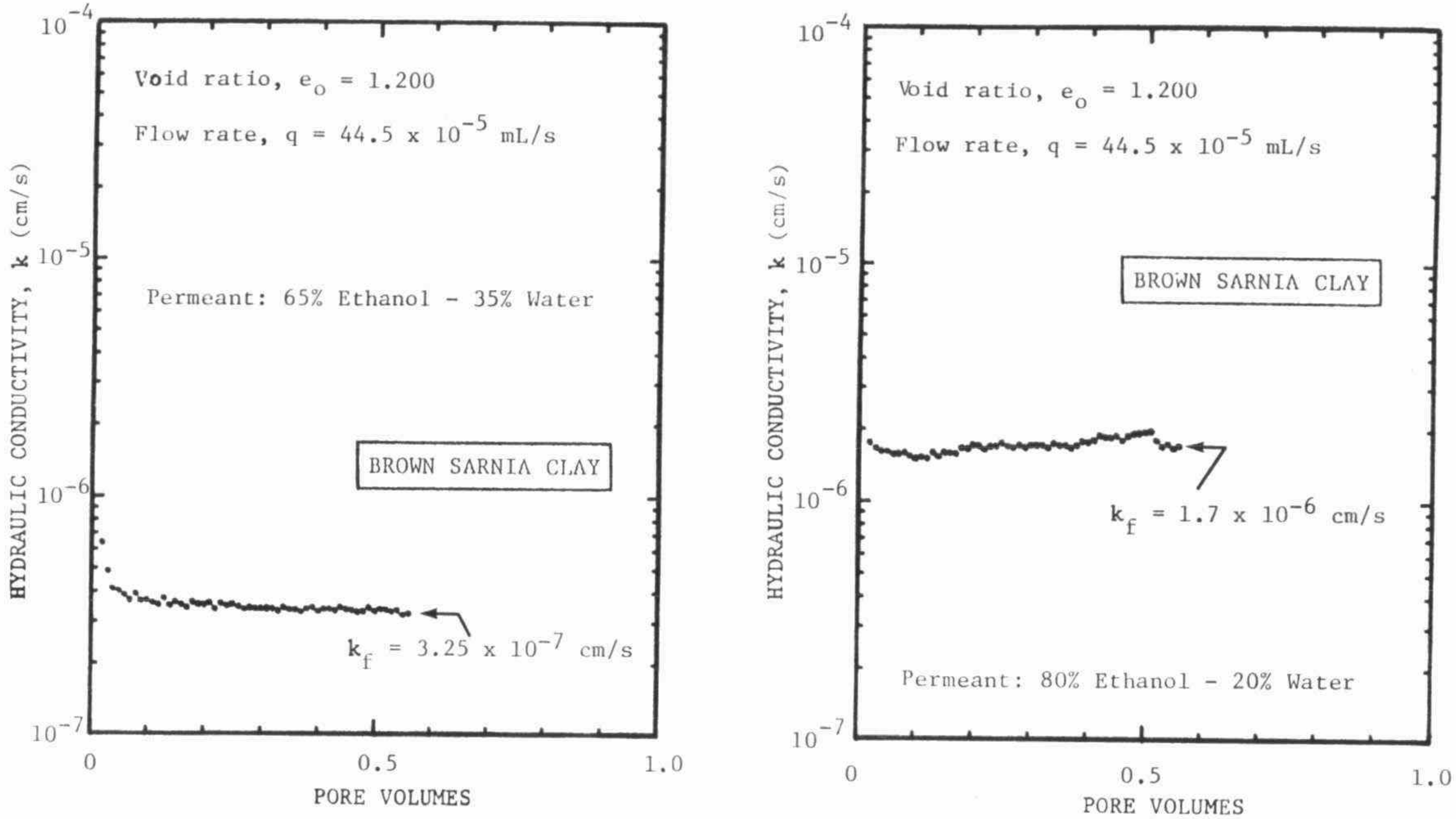

FIGURE D.15 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

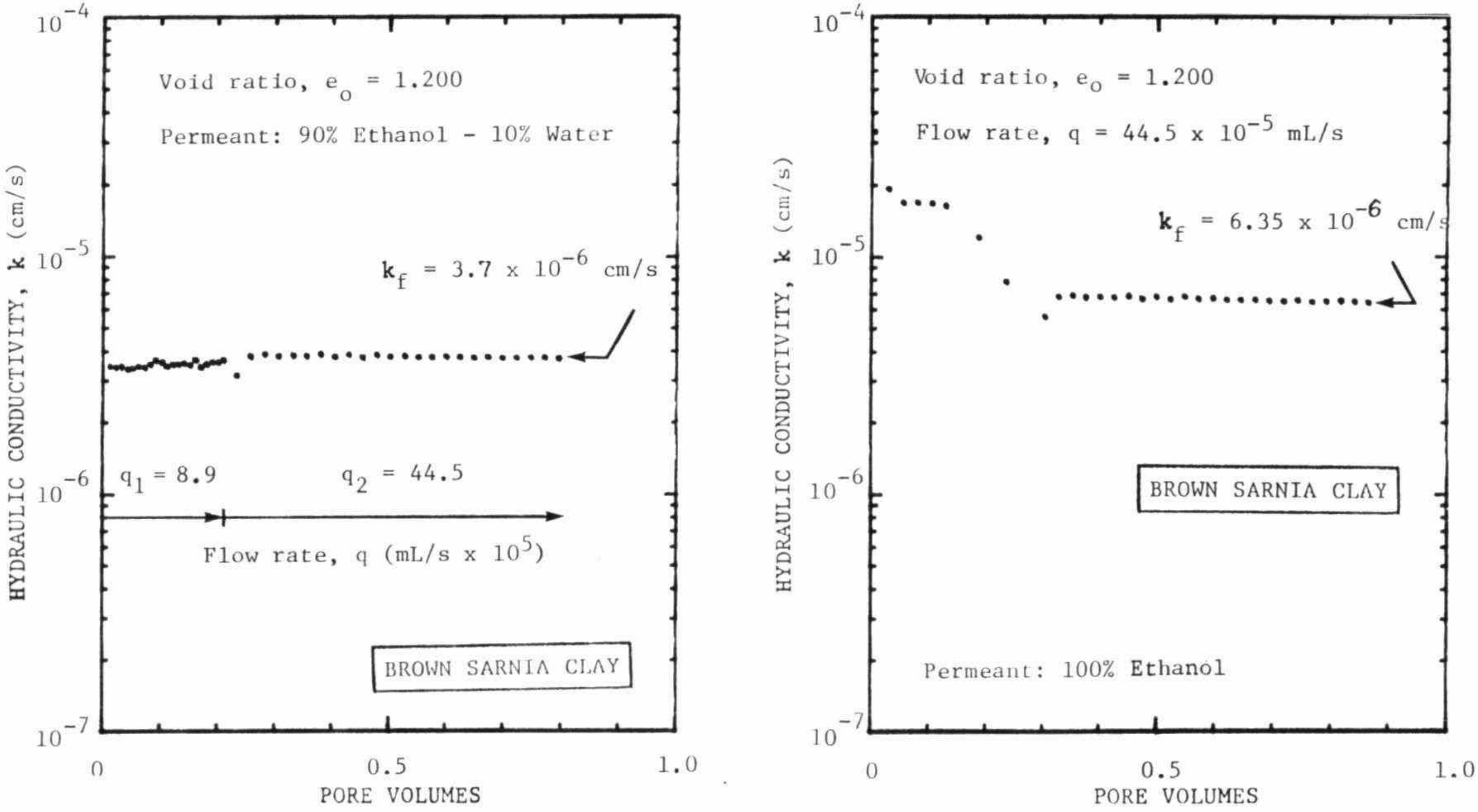

FIGURE D.16 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

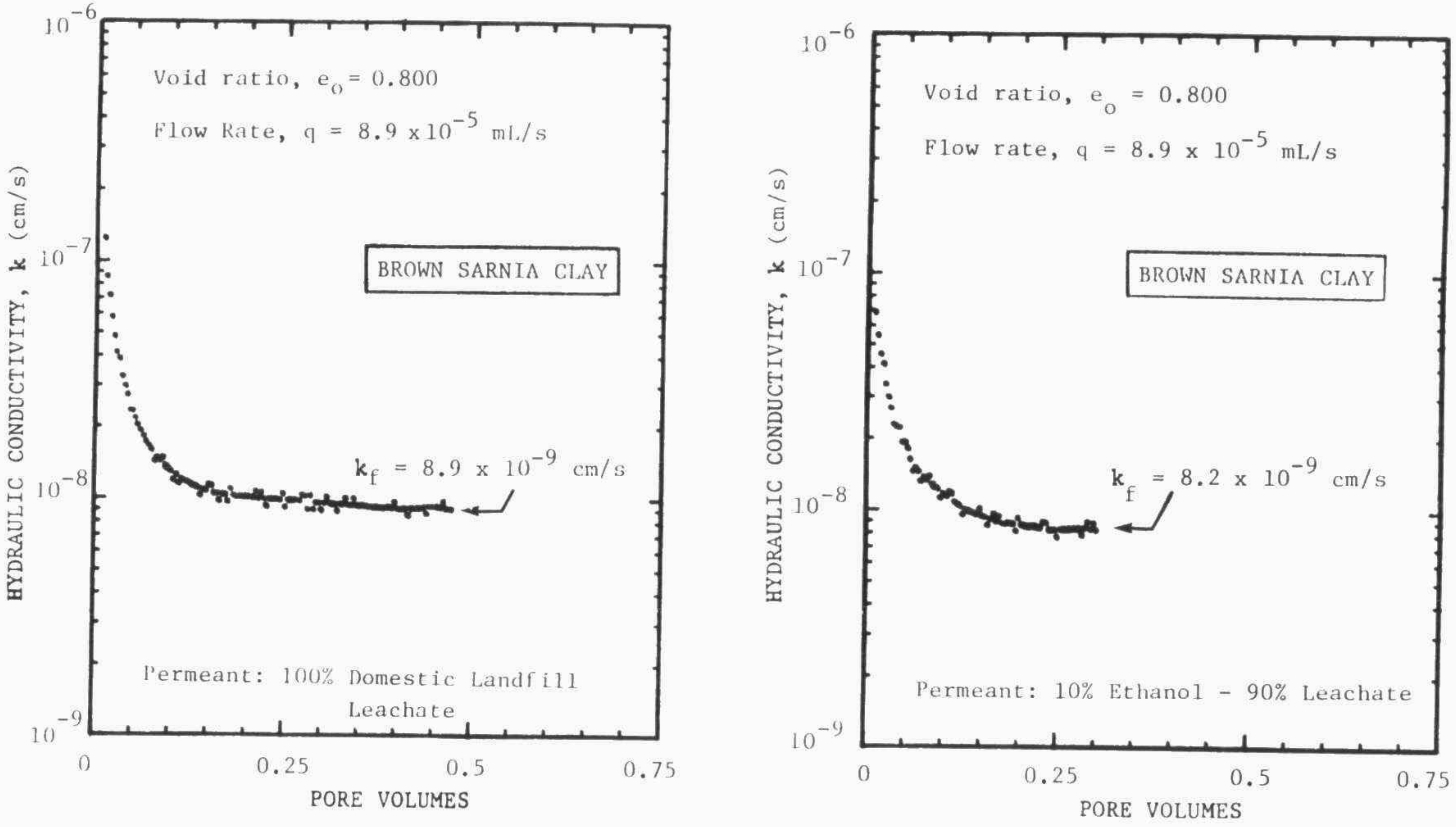

FIGURE D.17 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

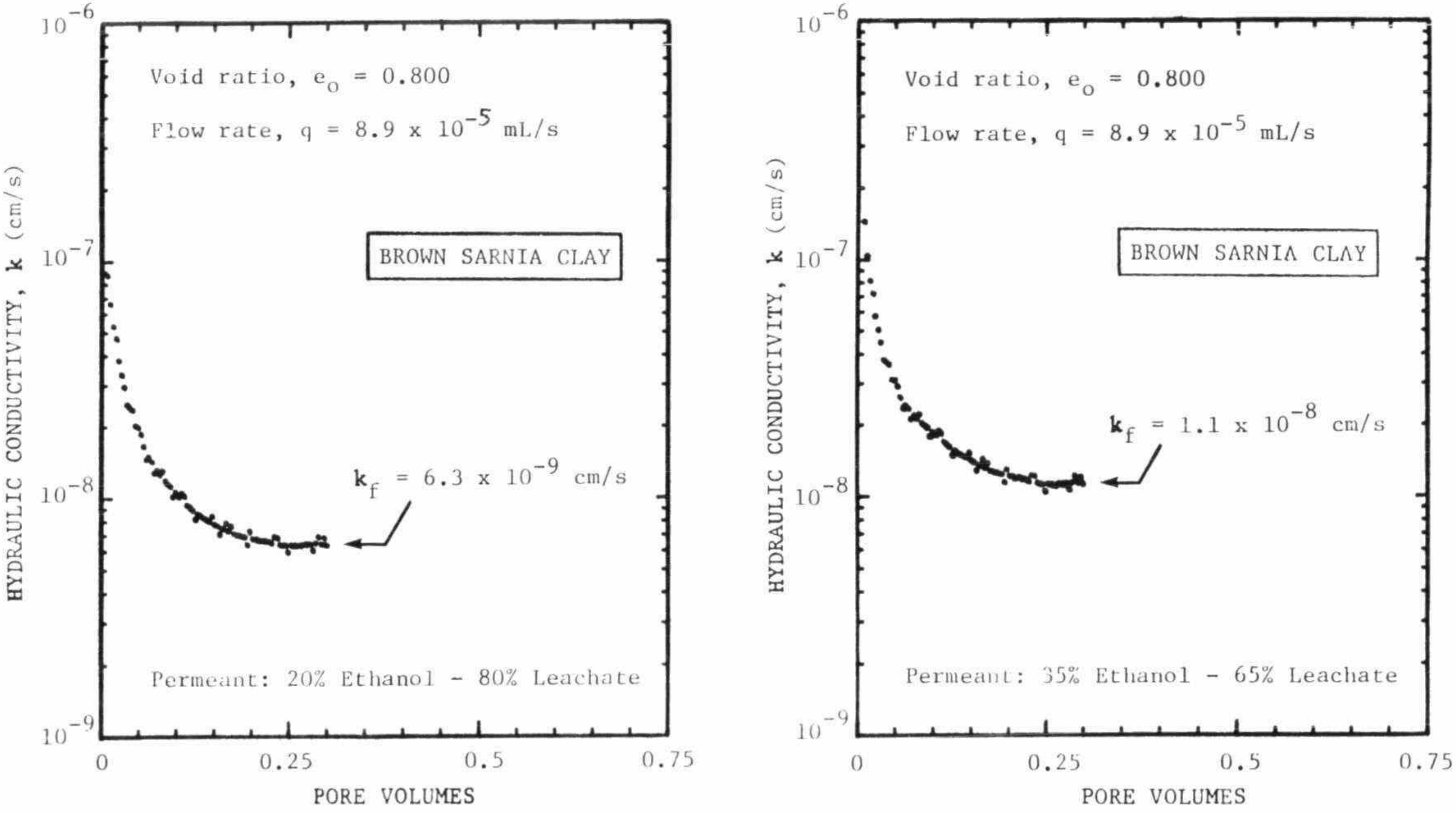

FIGURE D.18 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

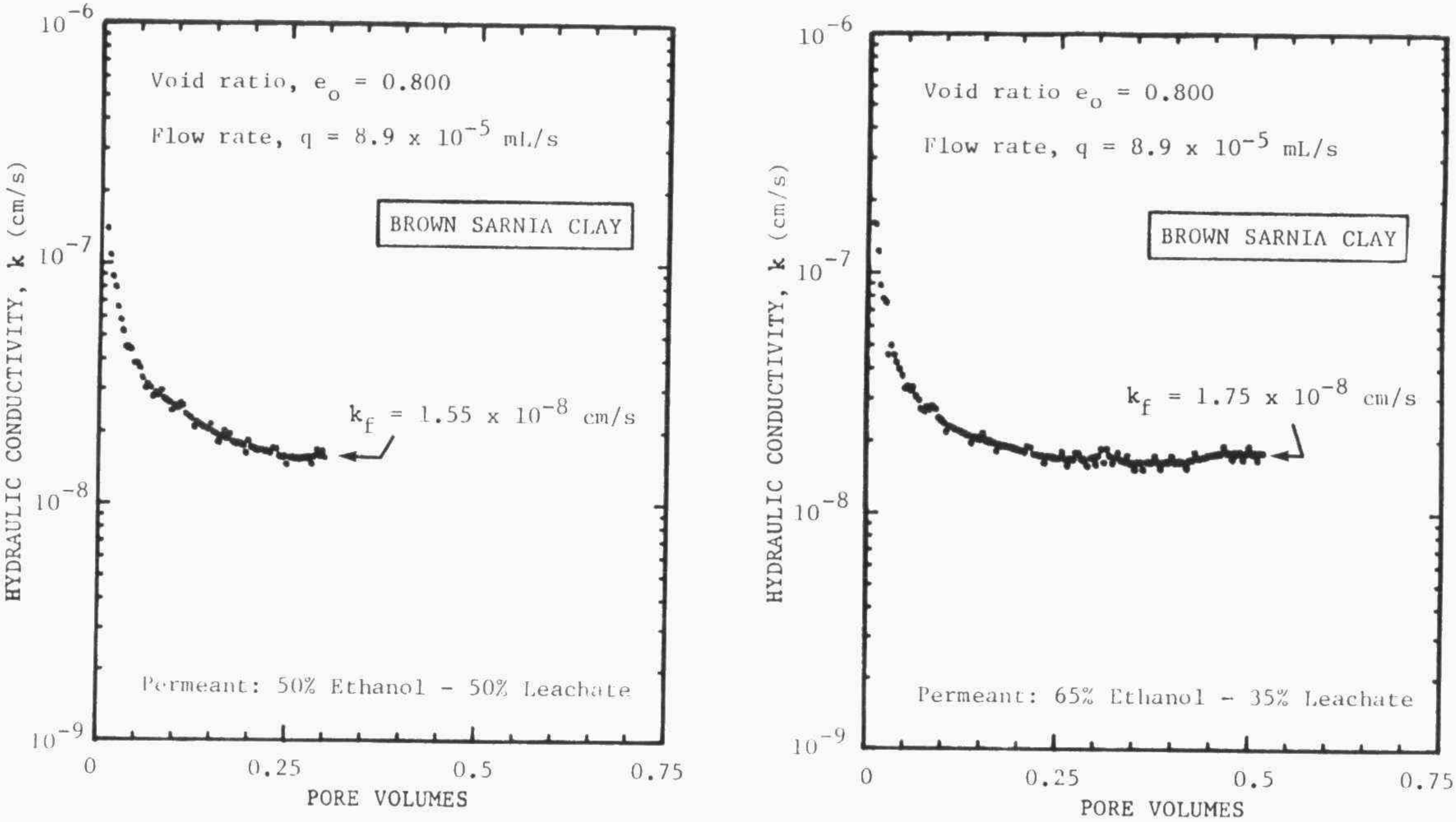

FIGURE D.19 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

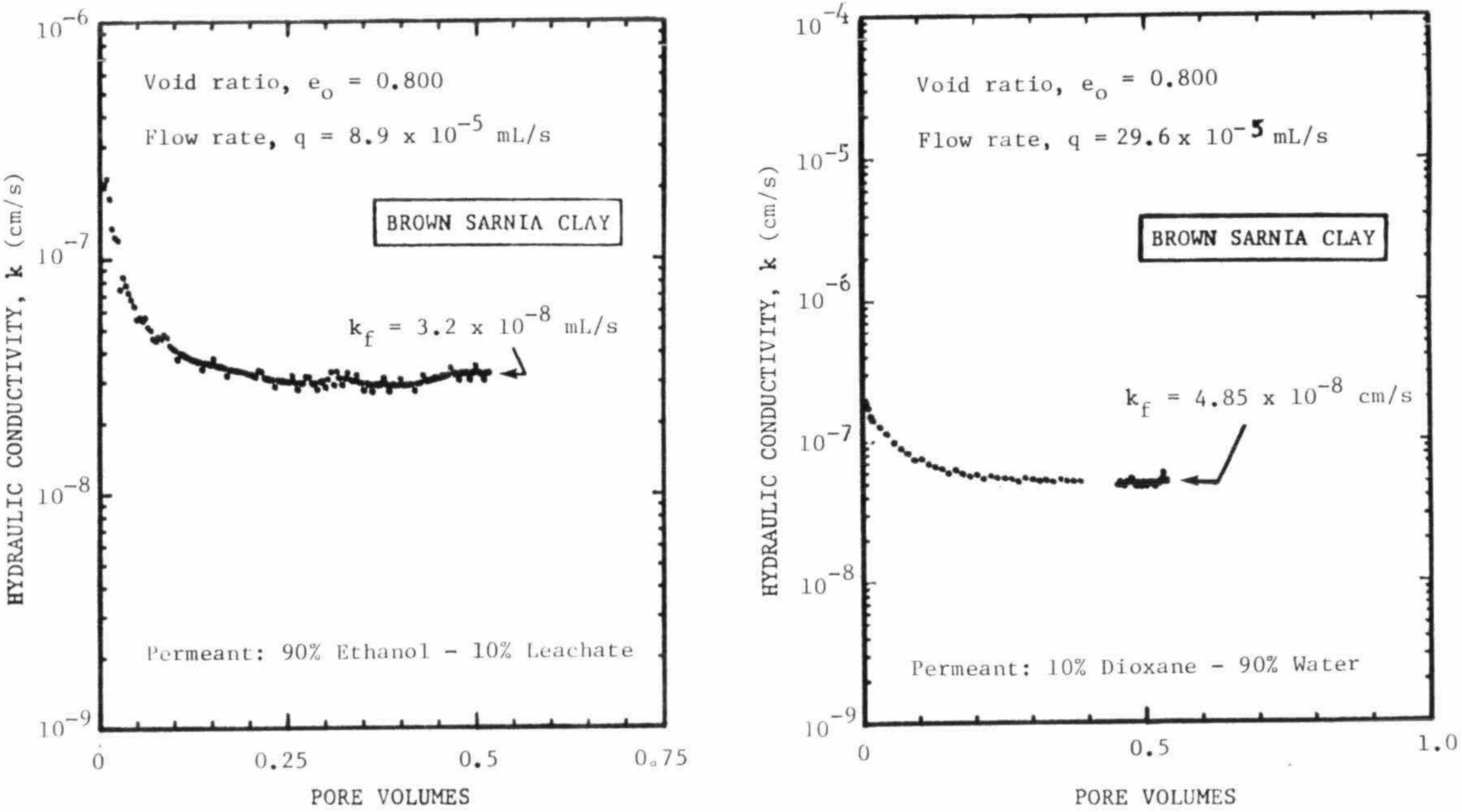

FIGURE D.20 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

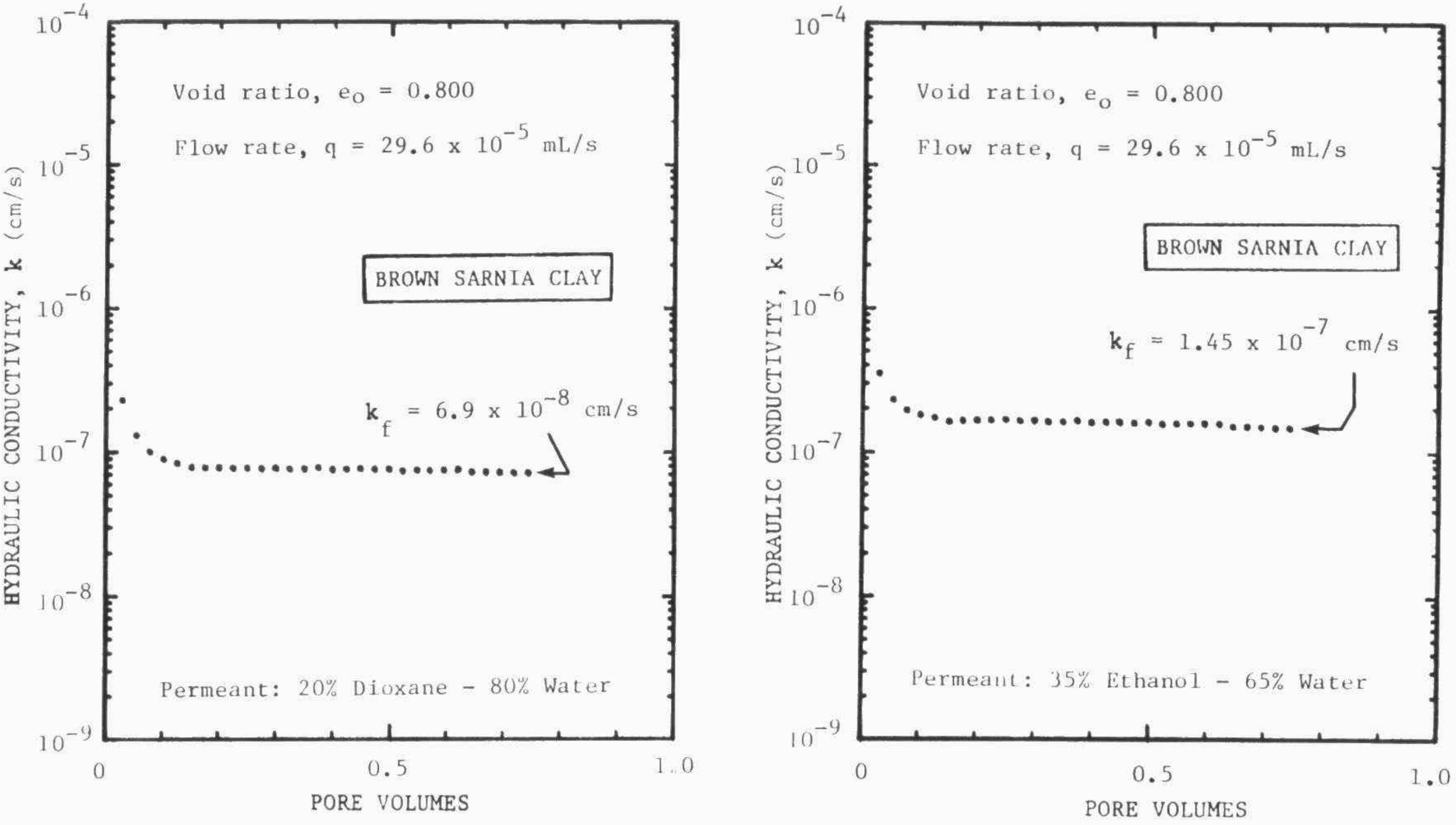

FIGURE D.21 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

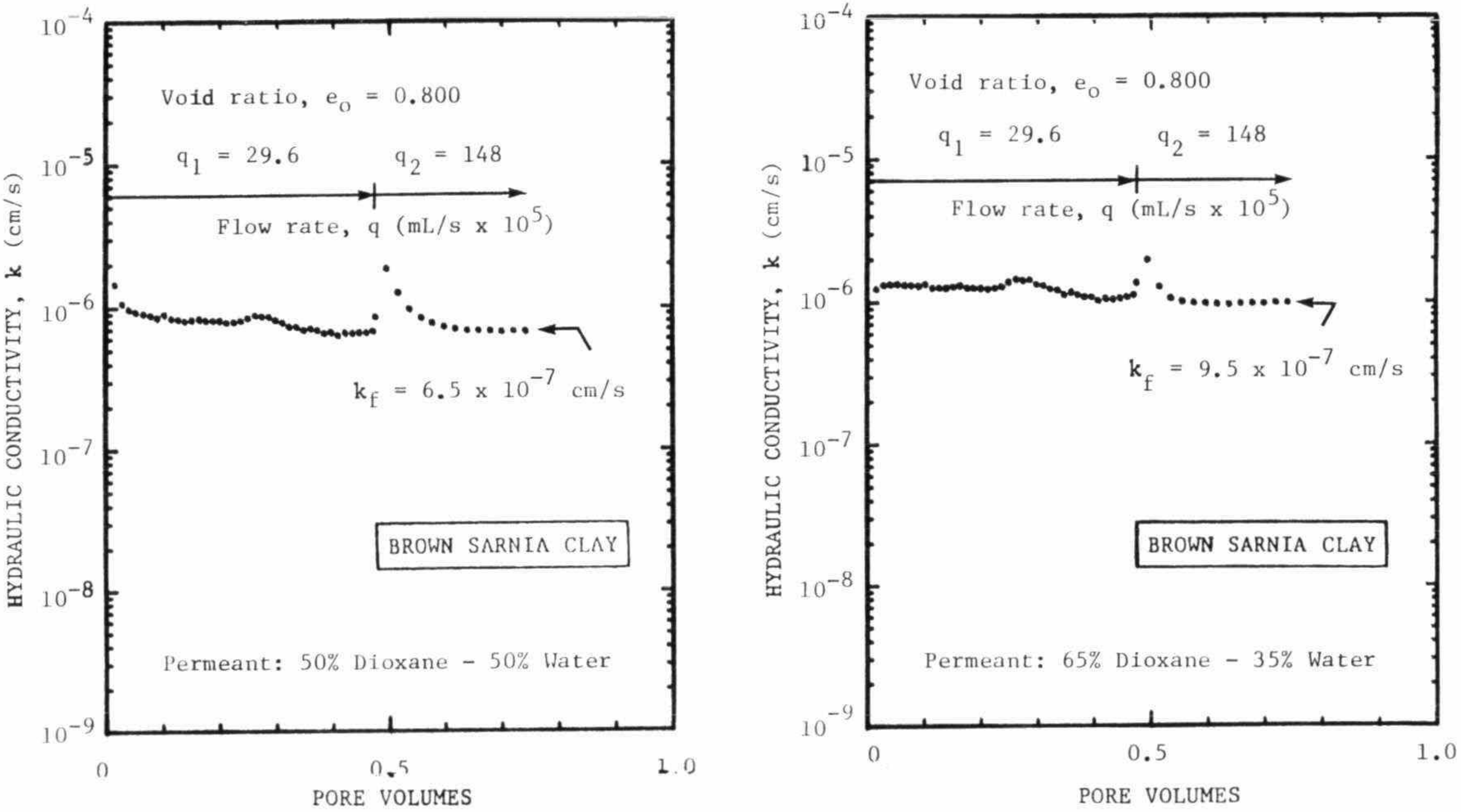

FIGURE D.22 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

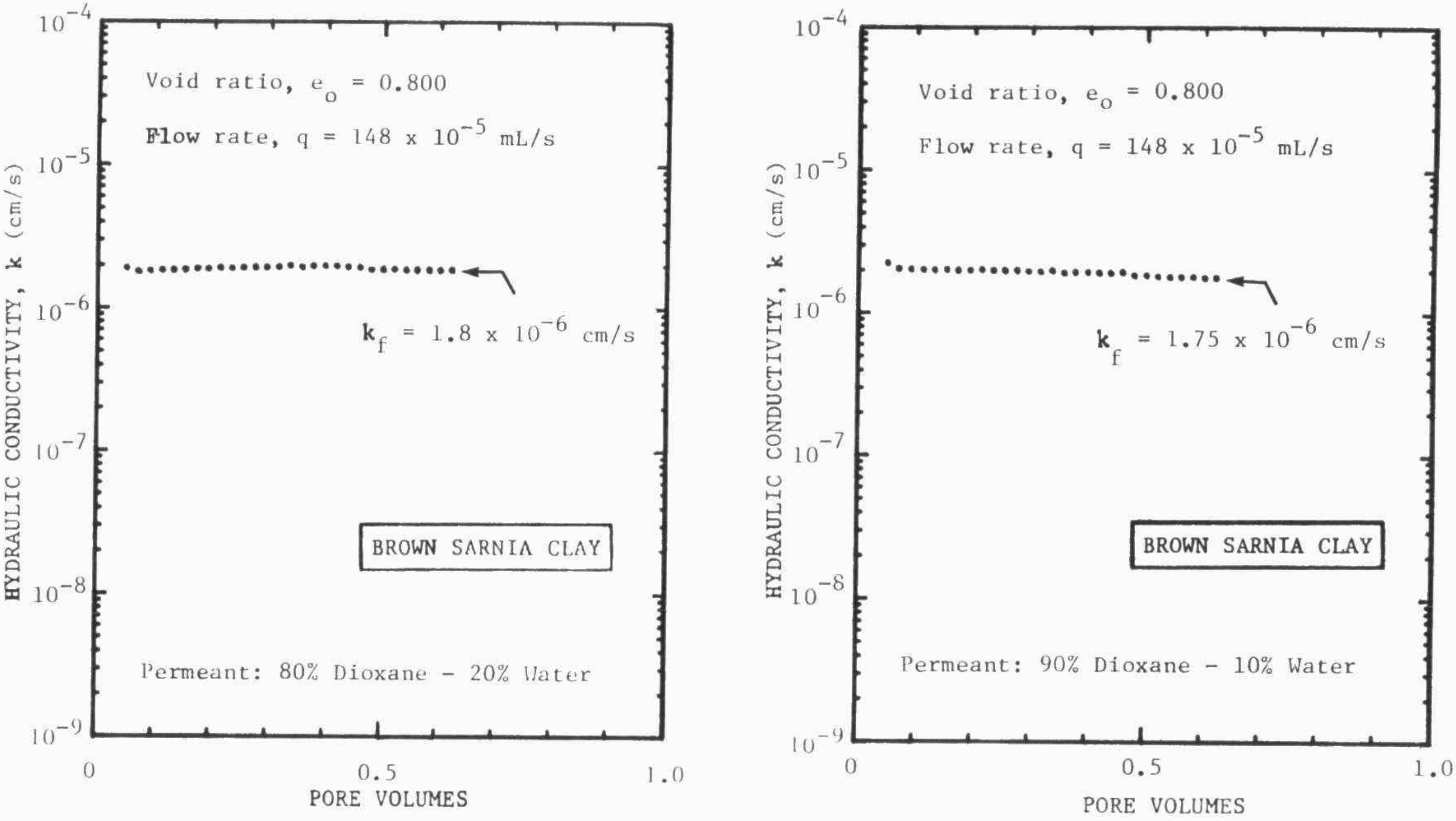

FIGURE D.23 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

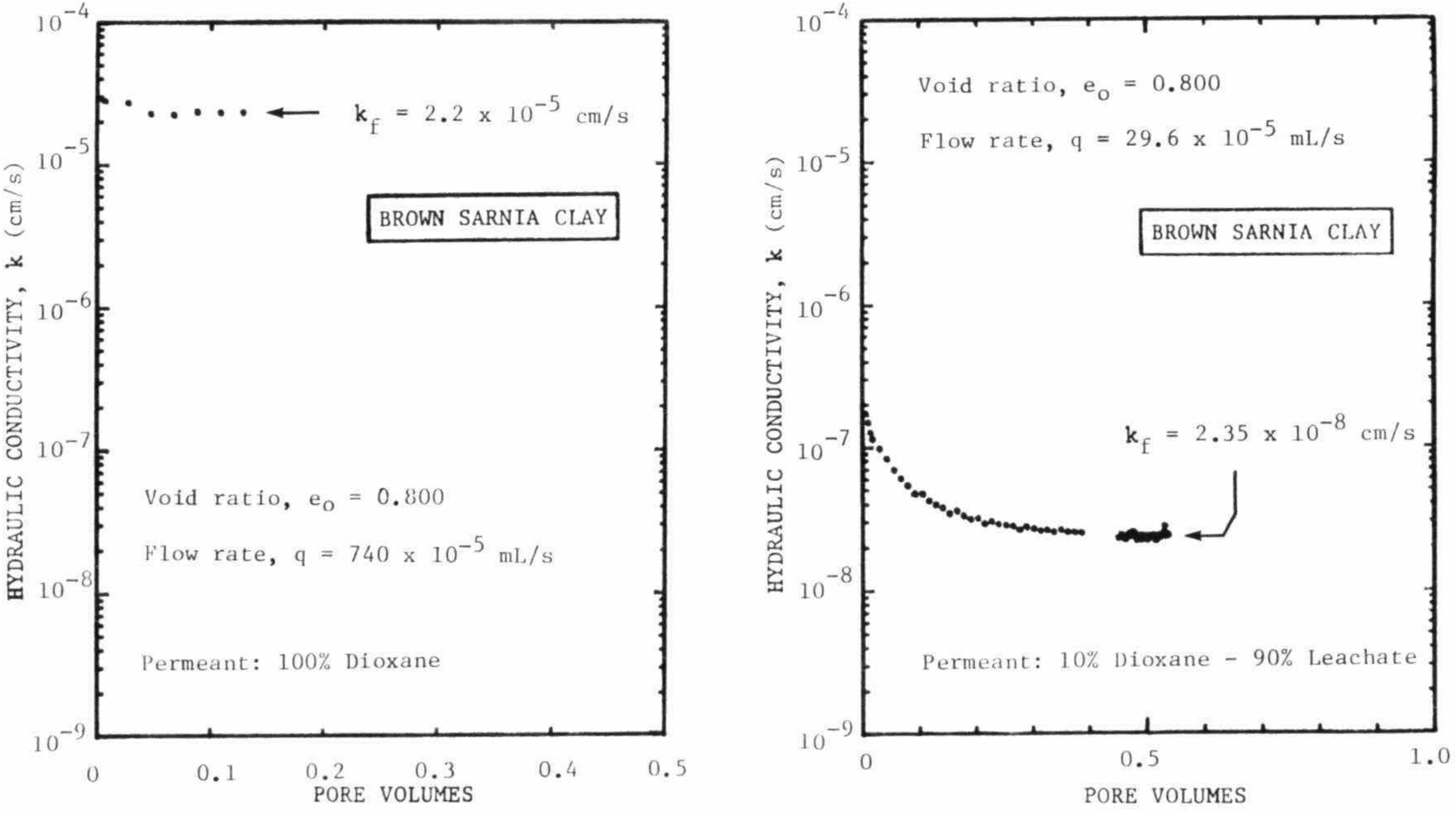

FIGURE D.24 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

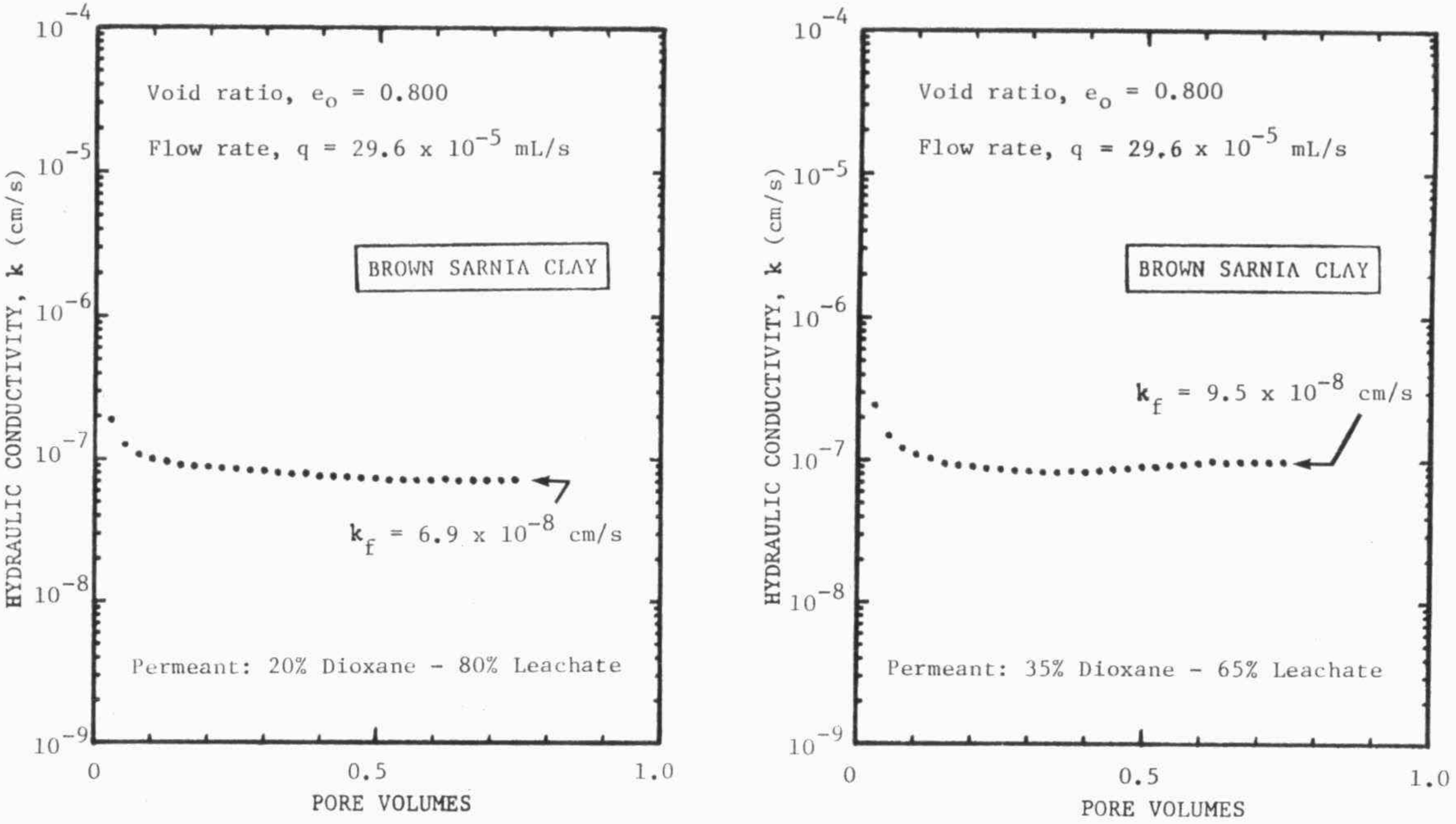

FIGURE D.25 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

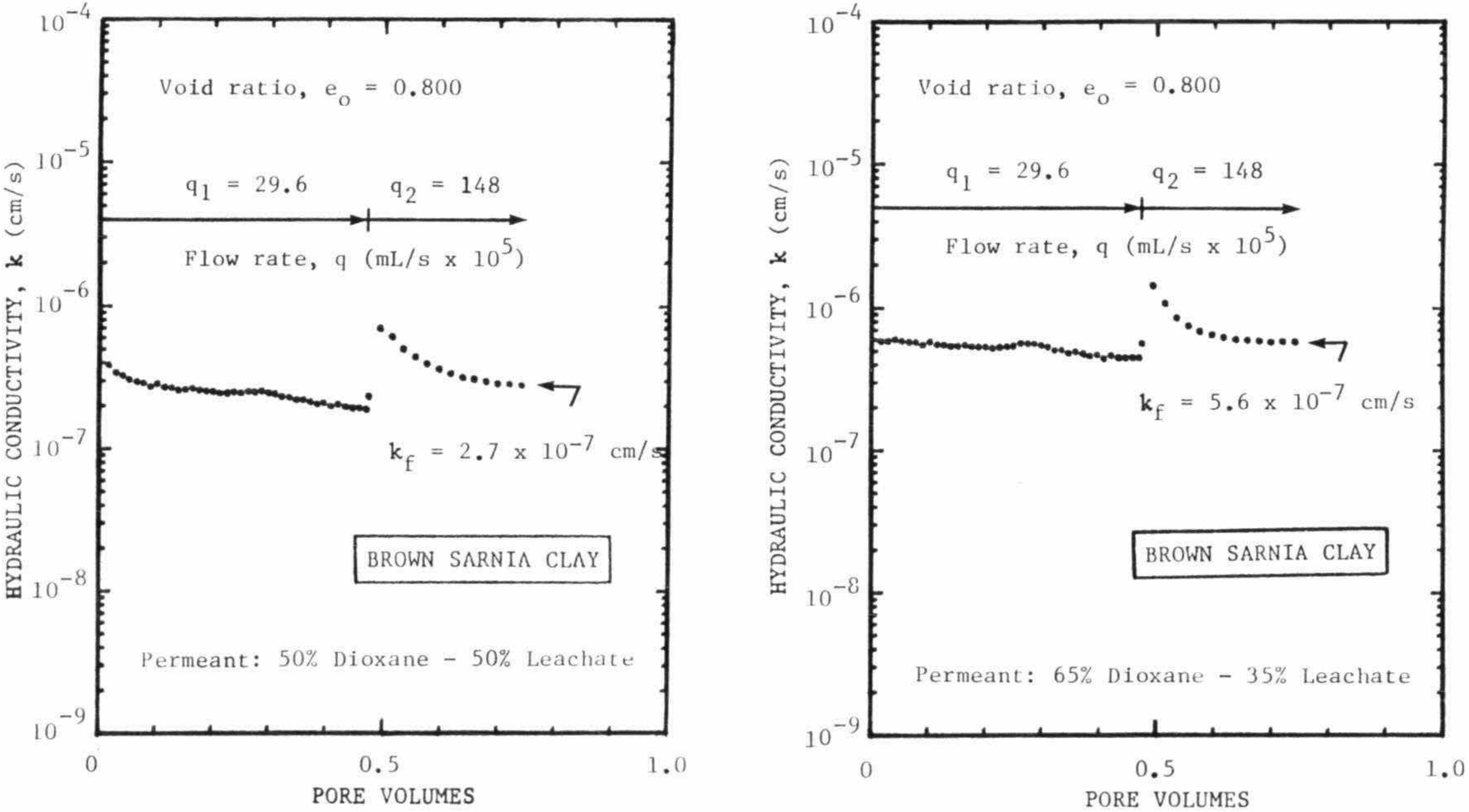

FIGURE D.26 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

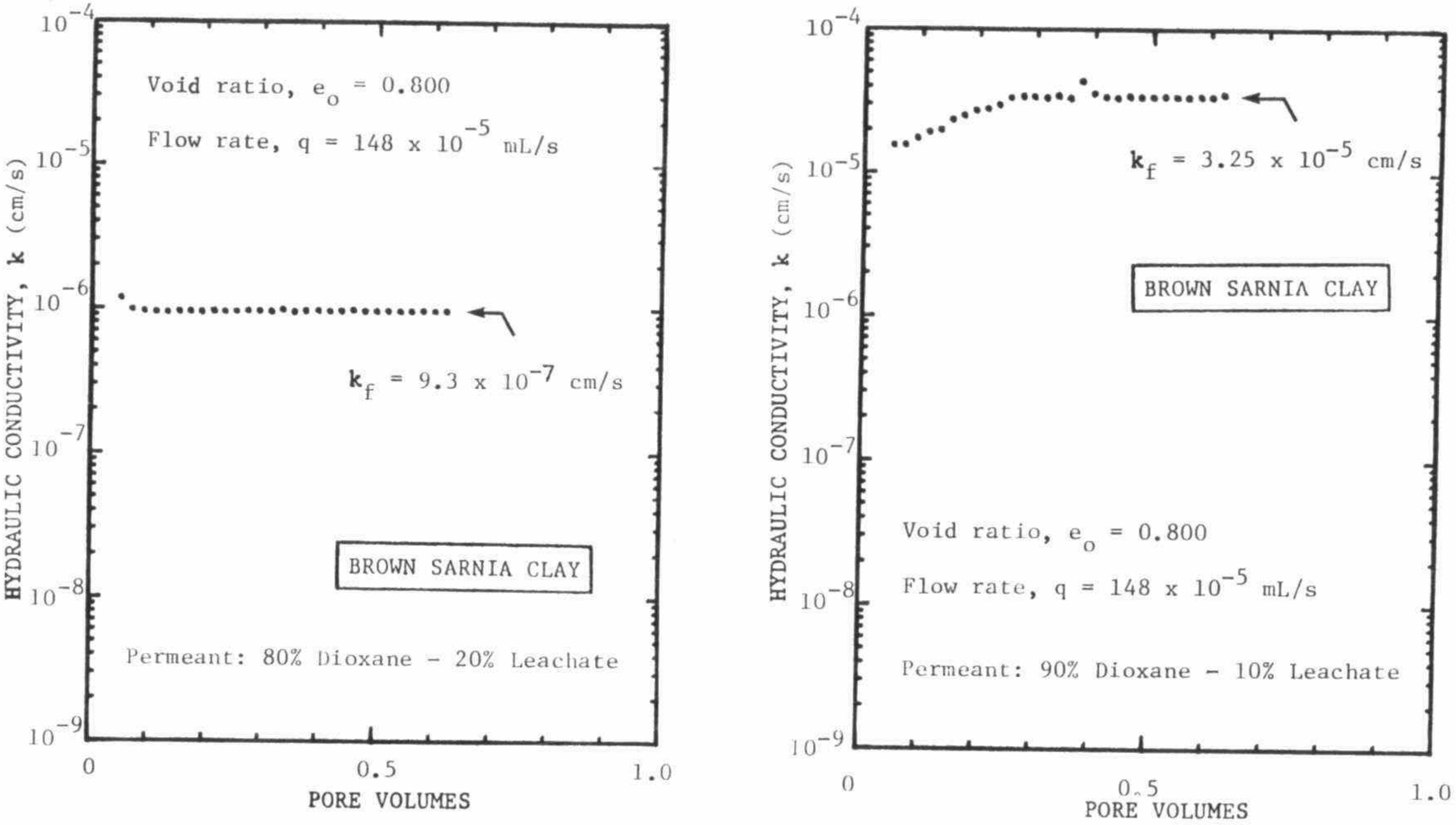

FIGURE D.27 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

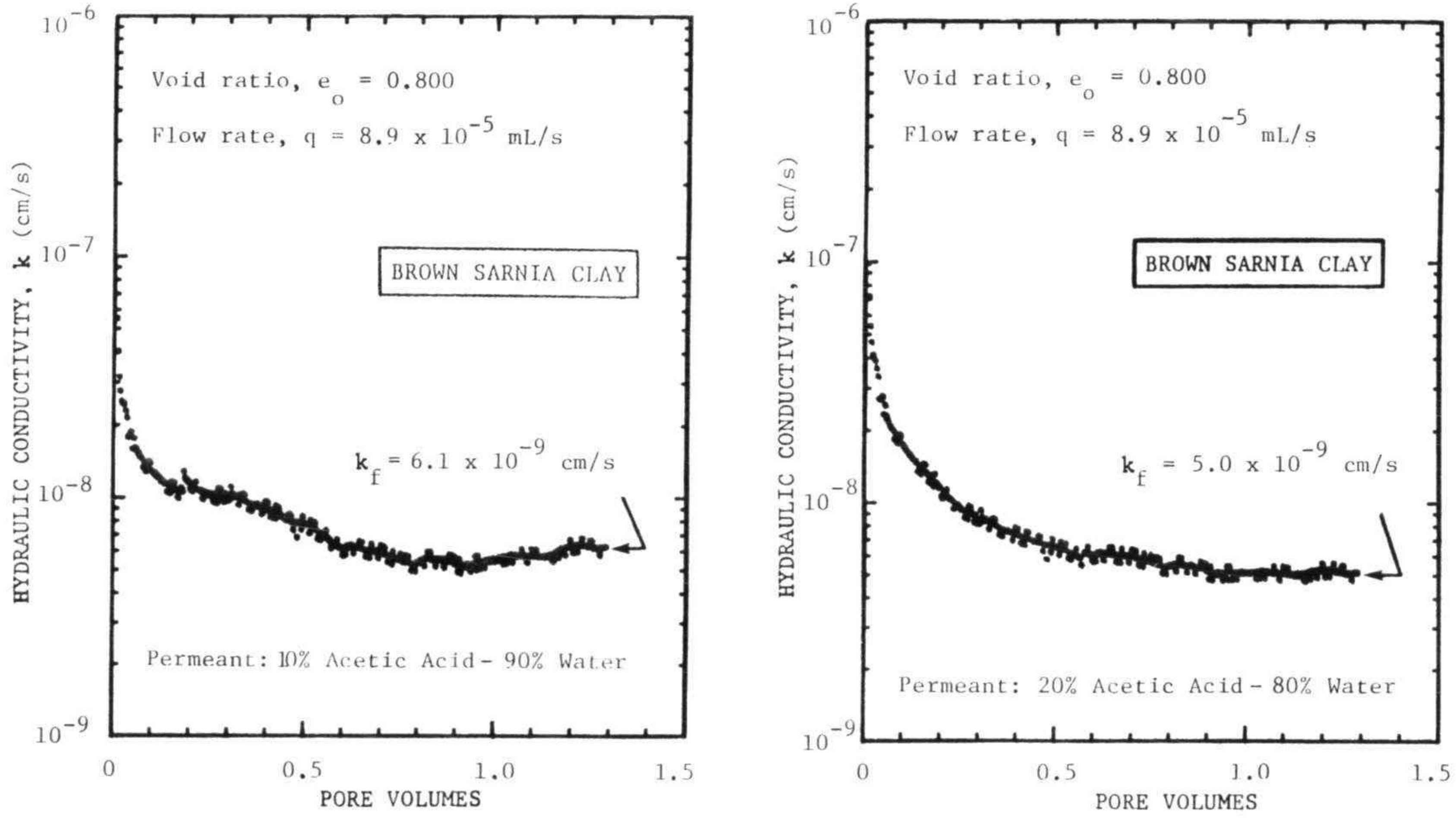

FIGURE D.28 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

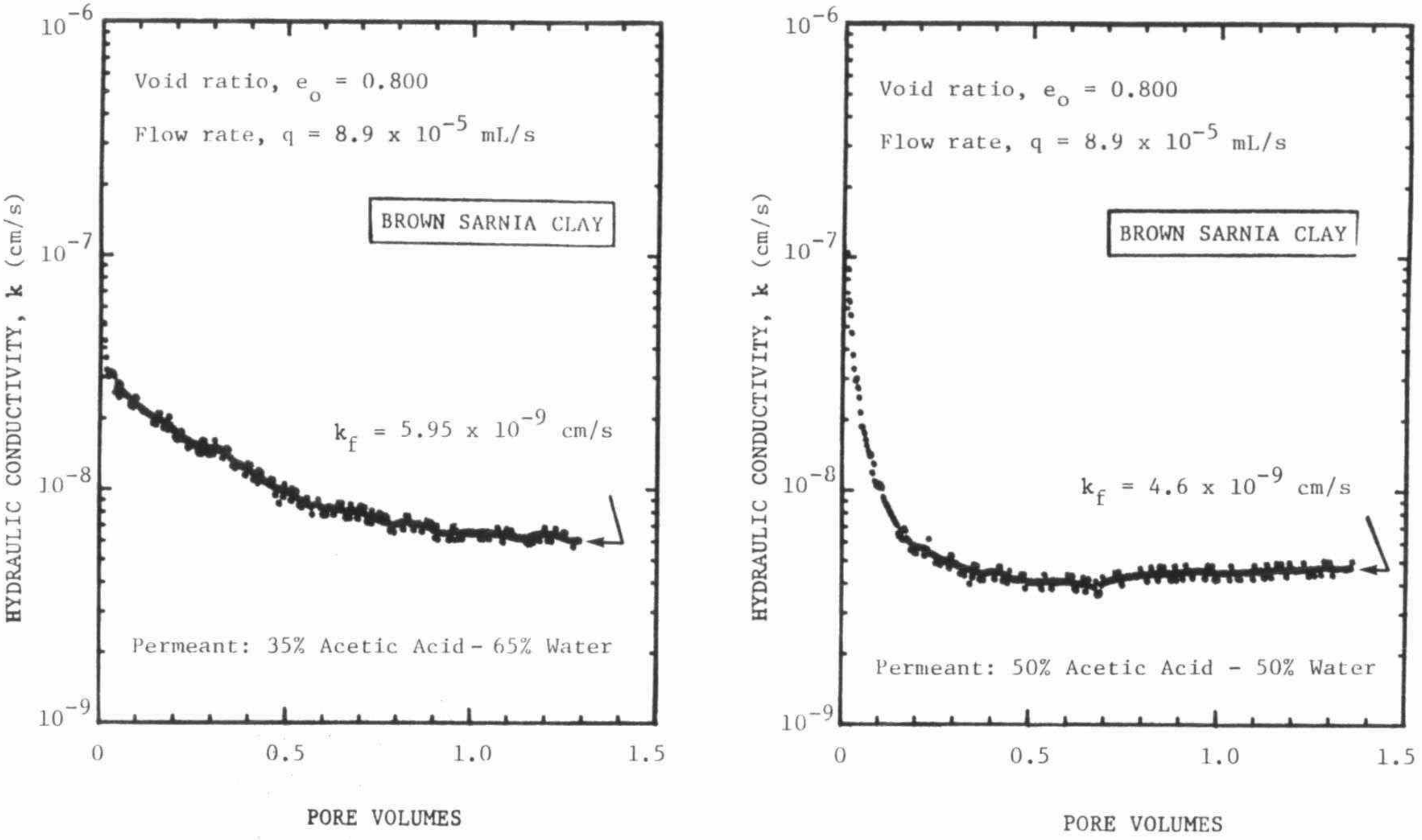

FIGURE D.29 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

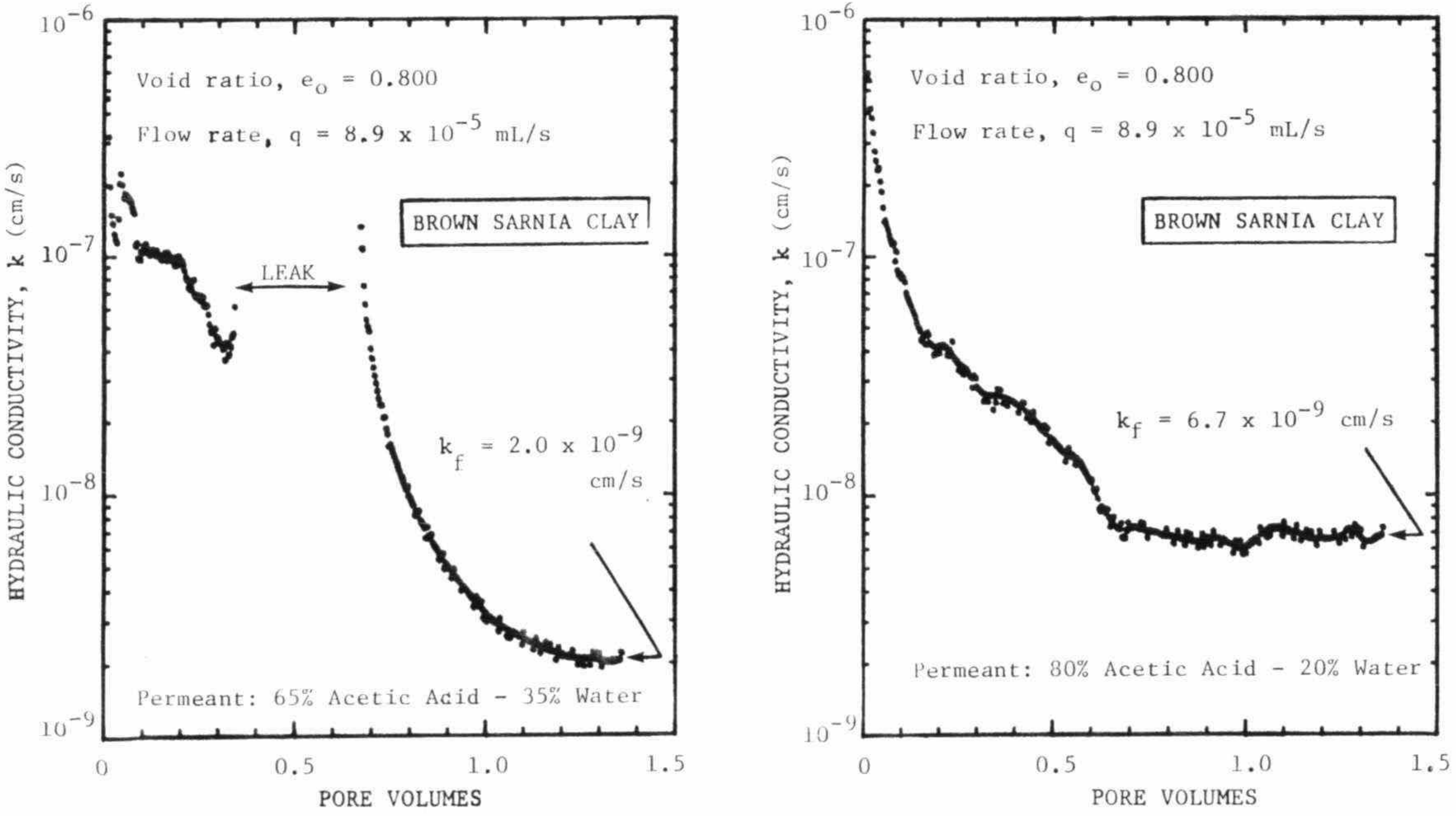

FIGURE D.30 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

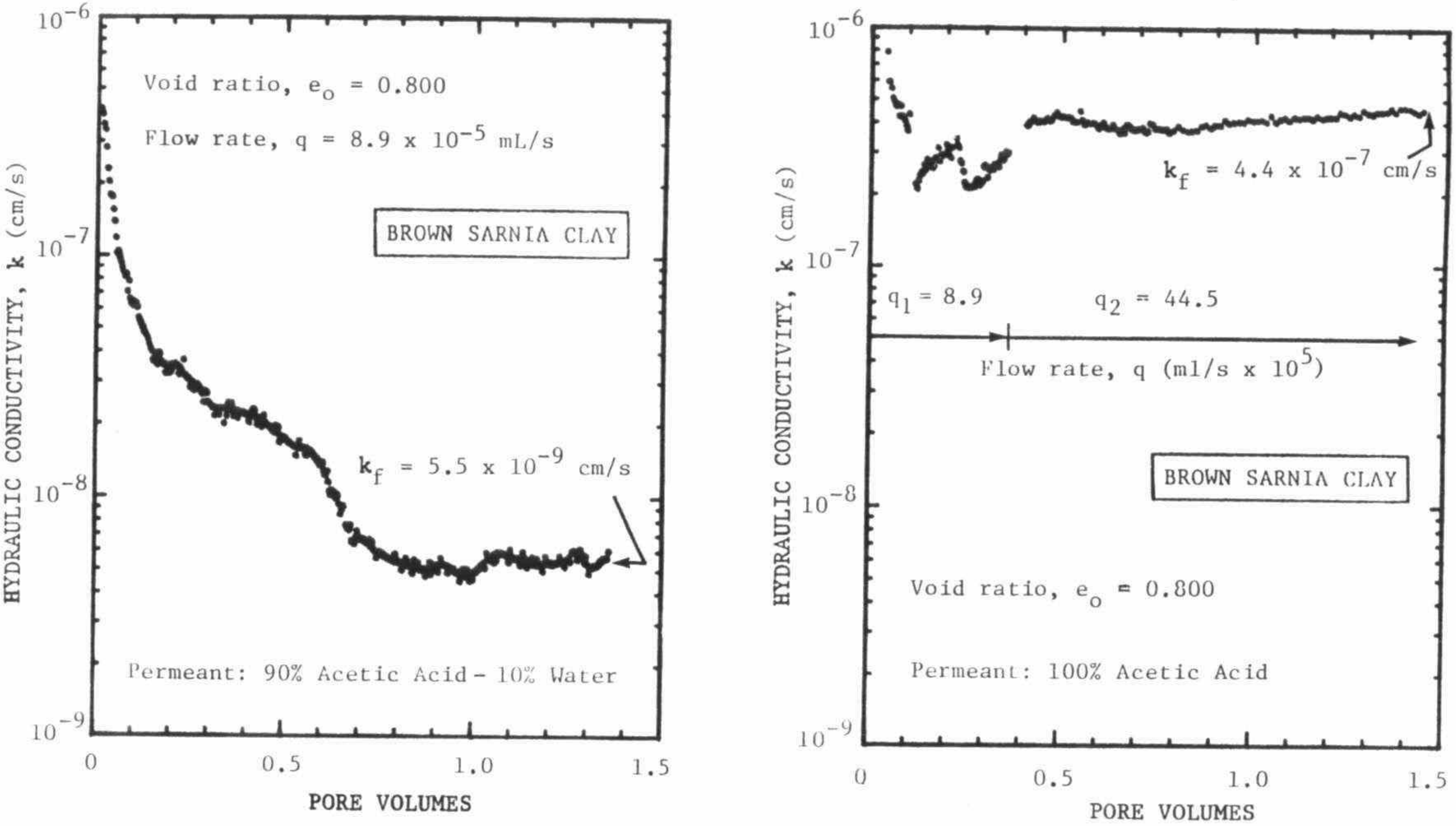

FIGURE D.31 HYDRAULIC CONDUCTIVITY VS PORE VOLUMES FOR CLAY/PERMEANT MIXTURES

APPENDIX E

HYDRAULIC CONDUCTIVITY CURVES FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH LEACHATE/ETHANOL MIXTURES

This appendix presents the results of hydraulic conductivity, settlement and effluent composition for tests performed on water-compacted brown Sarnia clays permeated with leachate/ethanol mixtures at the following static effective stresses: σ'_v = 0 kPa (Figures E.1 to E.6), σ'_v = 40 kPa (Figures E.7 to E.10), σ'_v = 80 kPa (Figures E.11 to E.14), σ'_v = 120 kPa (Figure E.15) and σ'_v = 160 kPa (Figures E.16 to E.19).

Figures E.20 and E.21 correspond to two additional tests for 100% ethanol through brown Sarnia clay at σ'_v = 10 kPa and σ'_v = 20 kPa.

Two duplicate tests for 40% ethanol and 100% ethanol at σ'_v = 0 kPa are shown in Figures E.22 and E.23).

The test results are discussed in Sections 5.3.1 of this report.

A special test carried out on water-compacted brown Sarnia clay permeated with a mixture of benzene, ethanol and leachate is shown in Figure E.24.

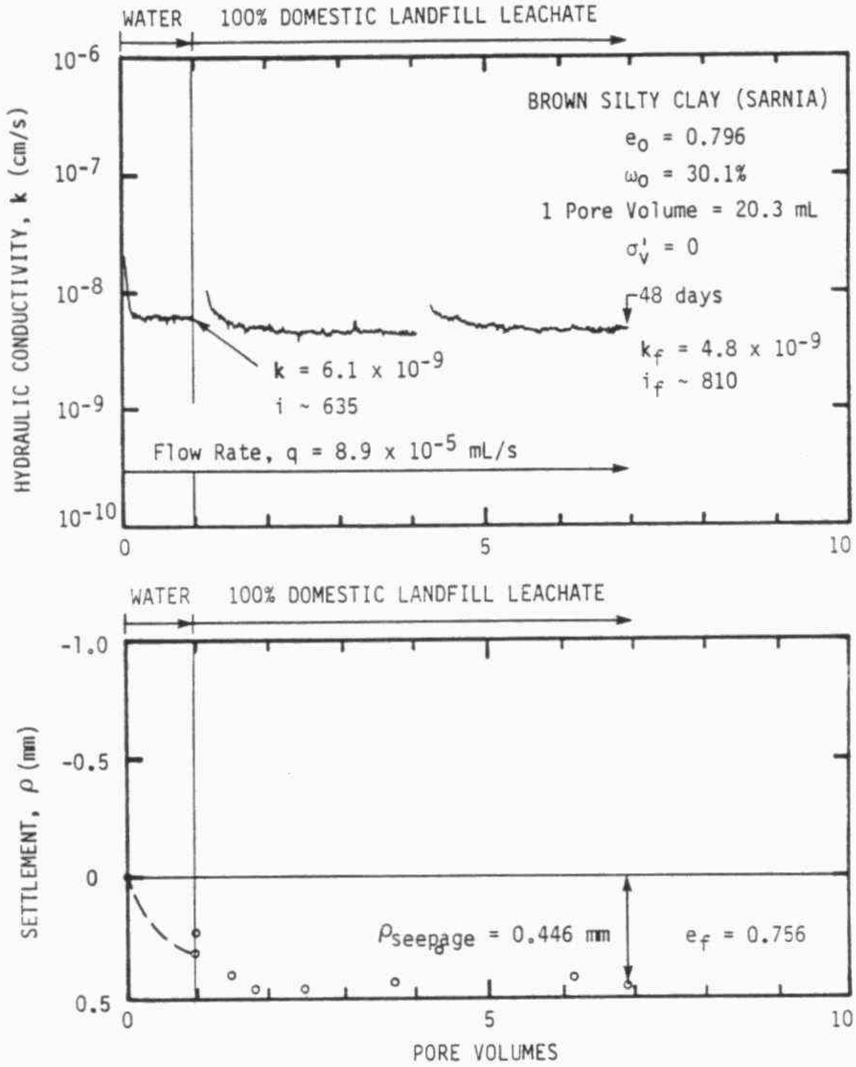

FIGURE E.1 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

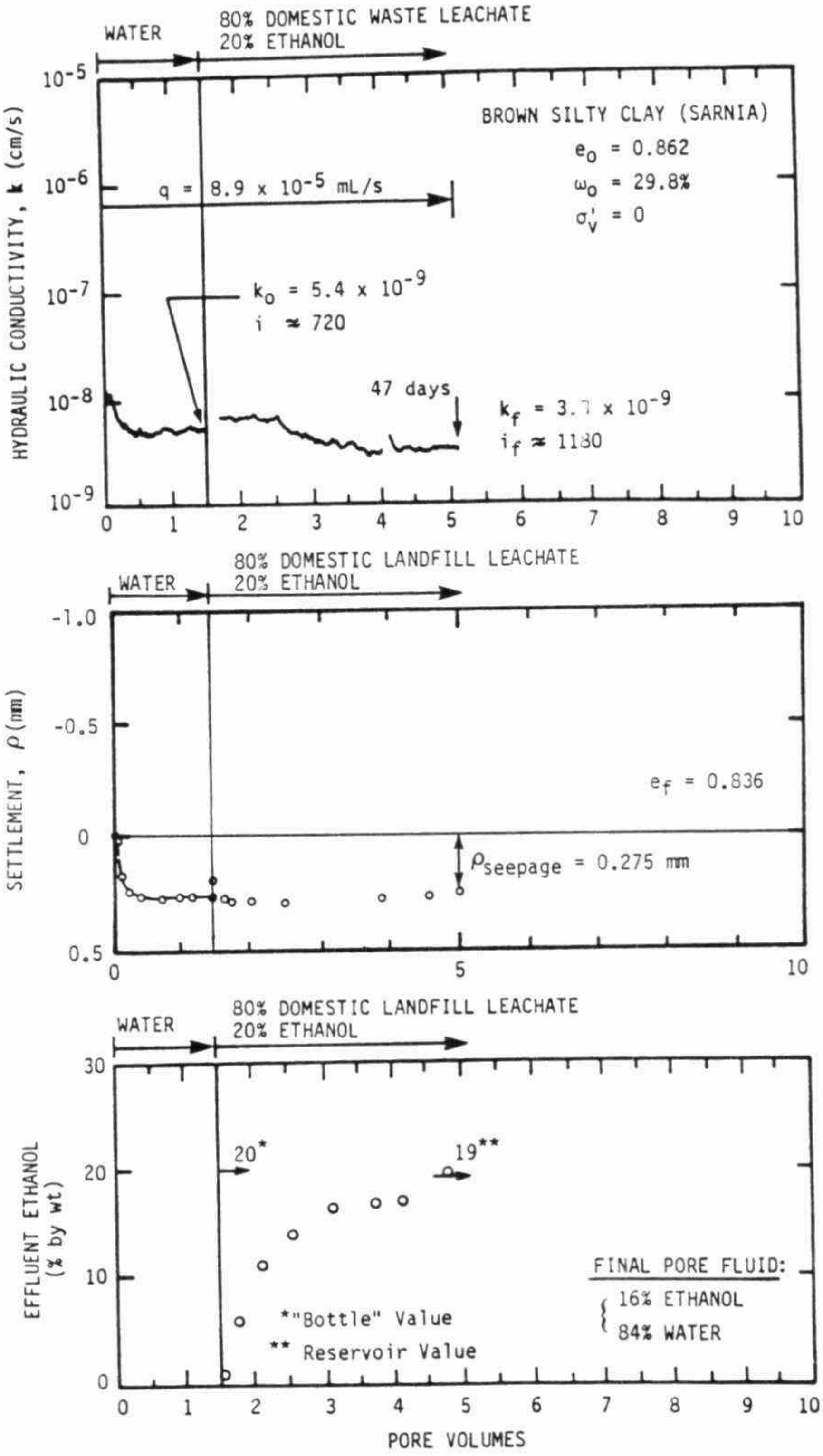

FIGURE E.2 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

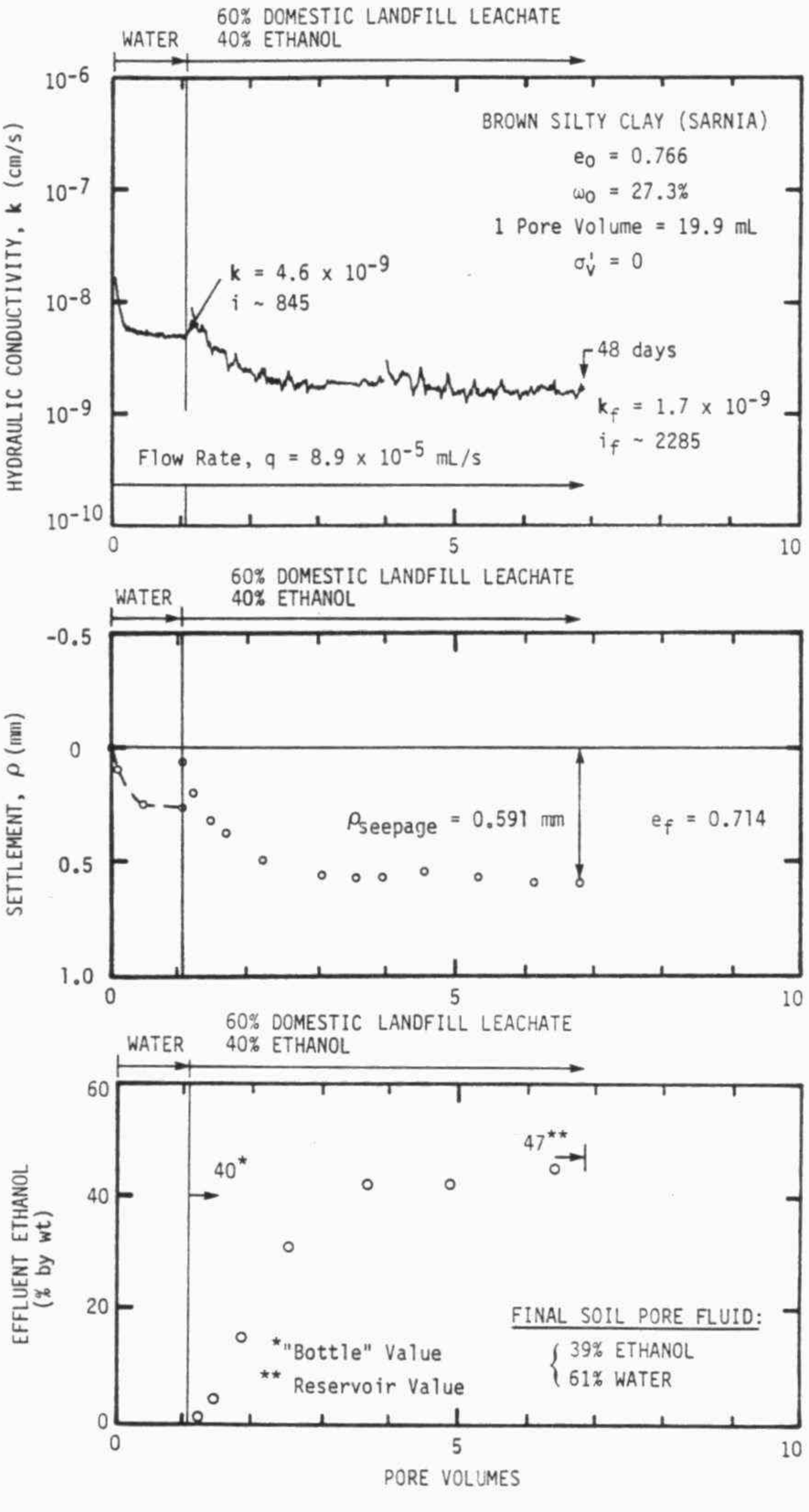

FIGURE E.3 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

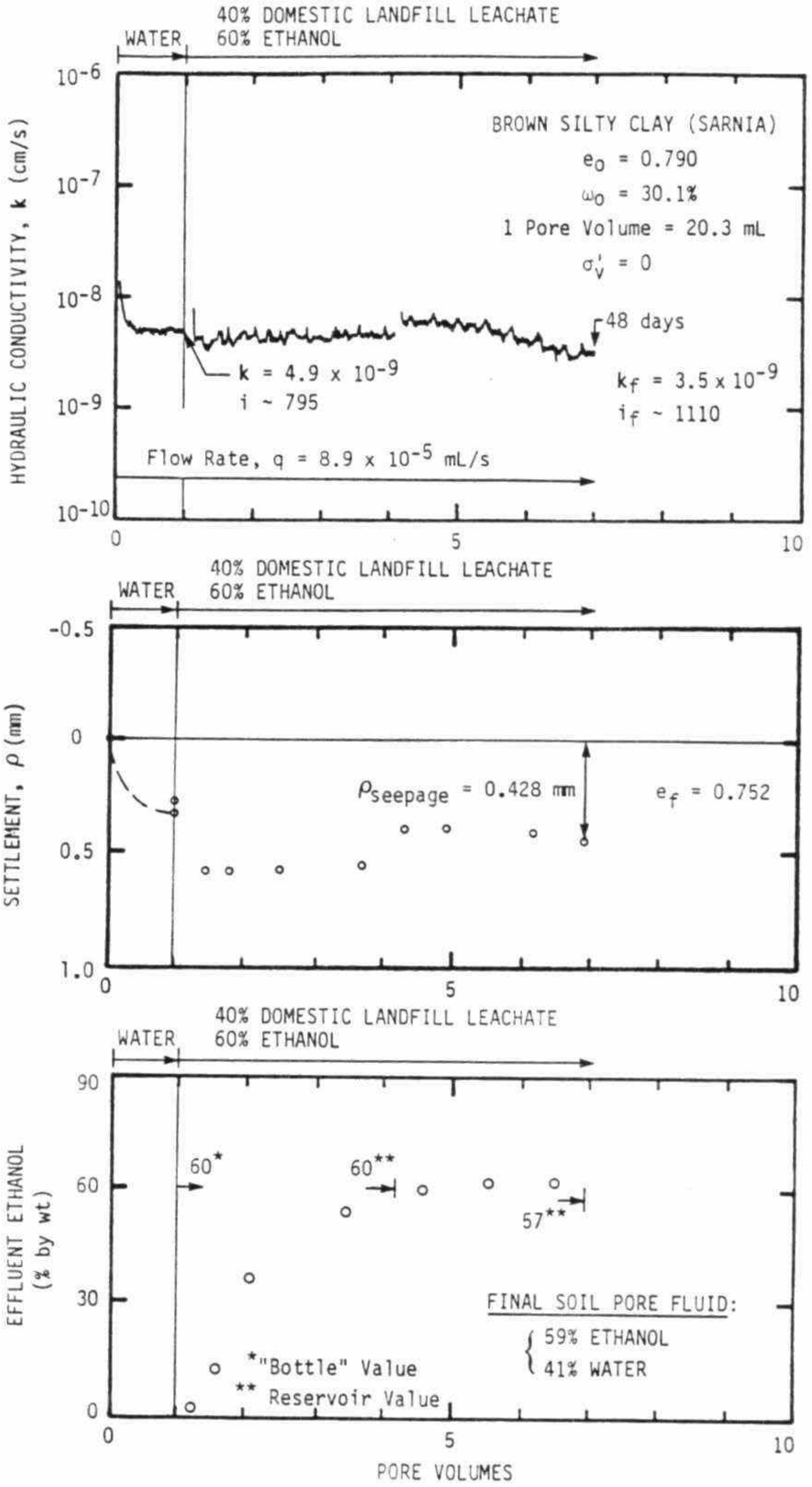

FIGURE E.4 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

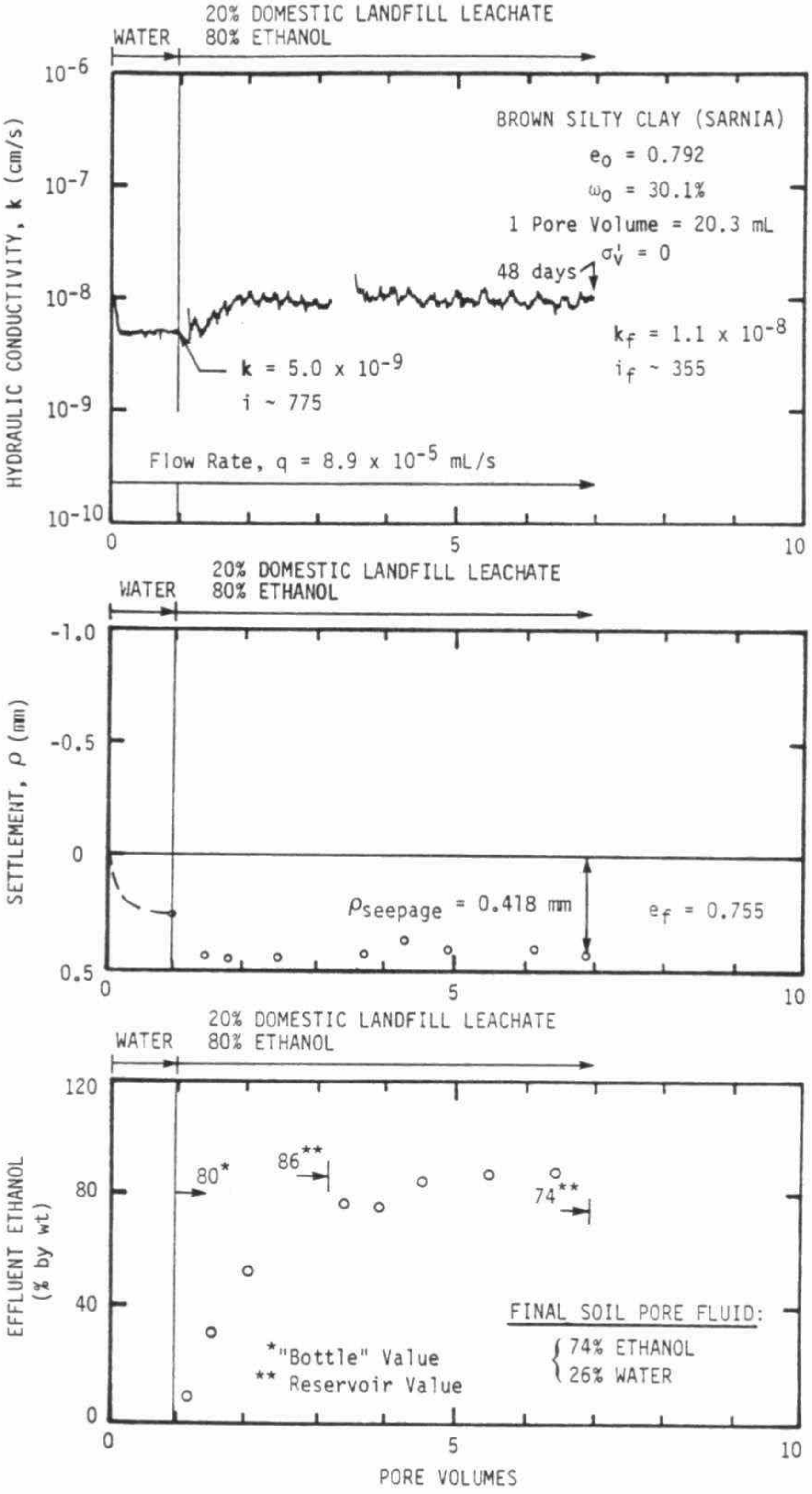

FIGURE E.5 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

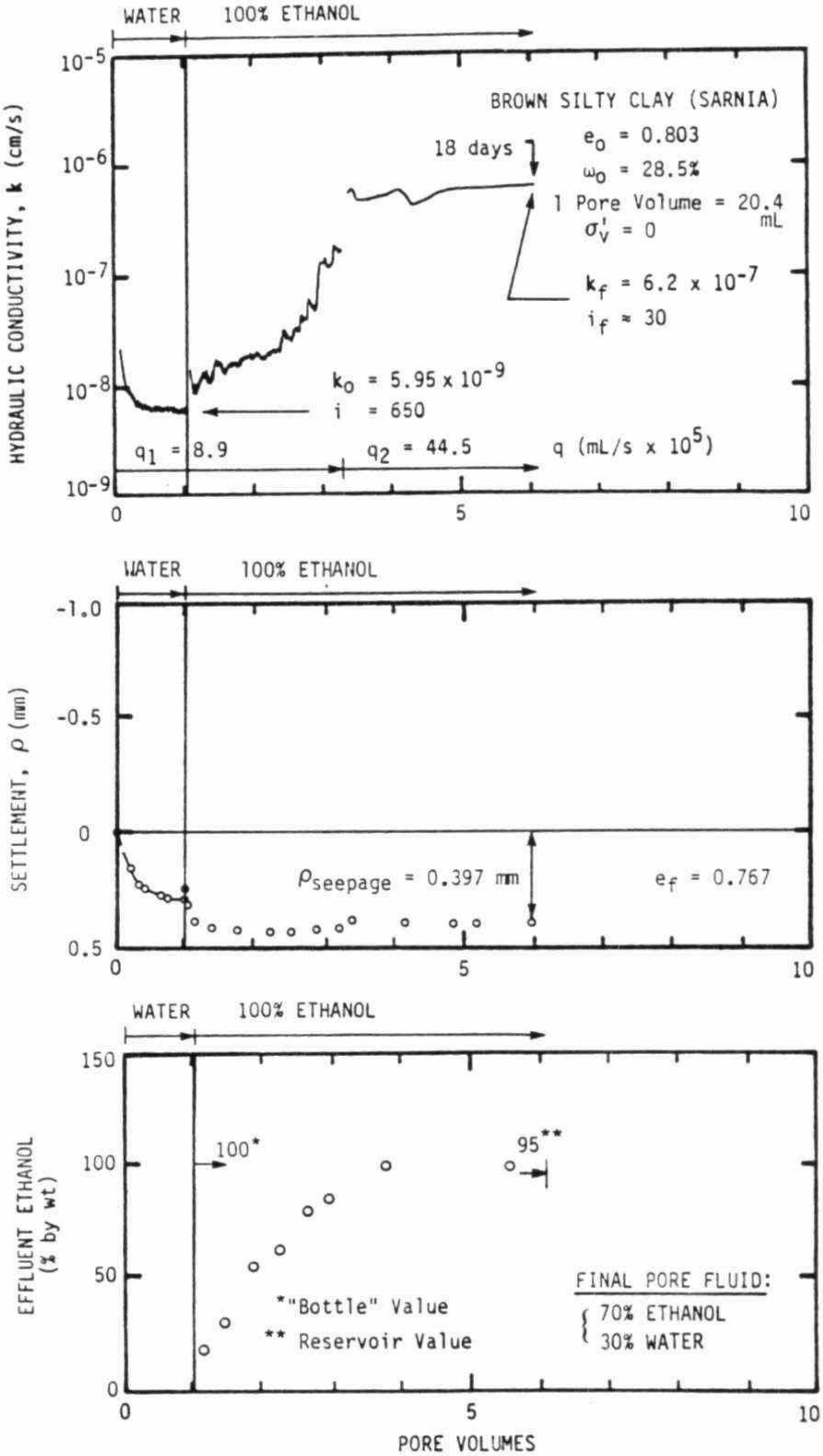

FIGURE E.6 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

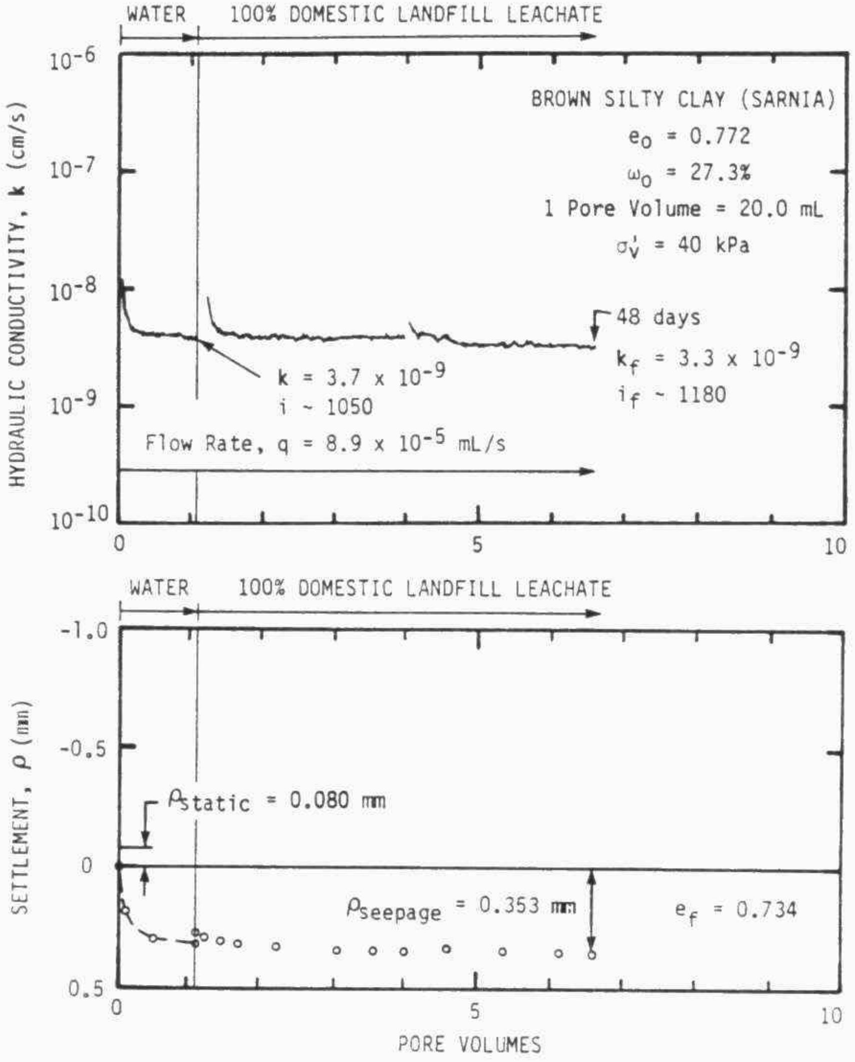

FIGURE E.7 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

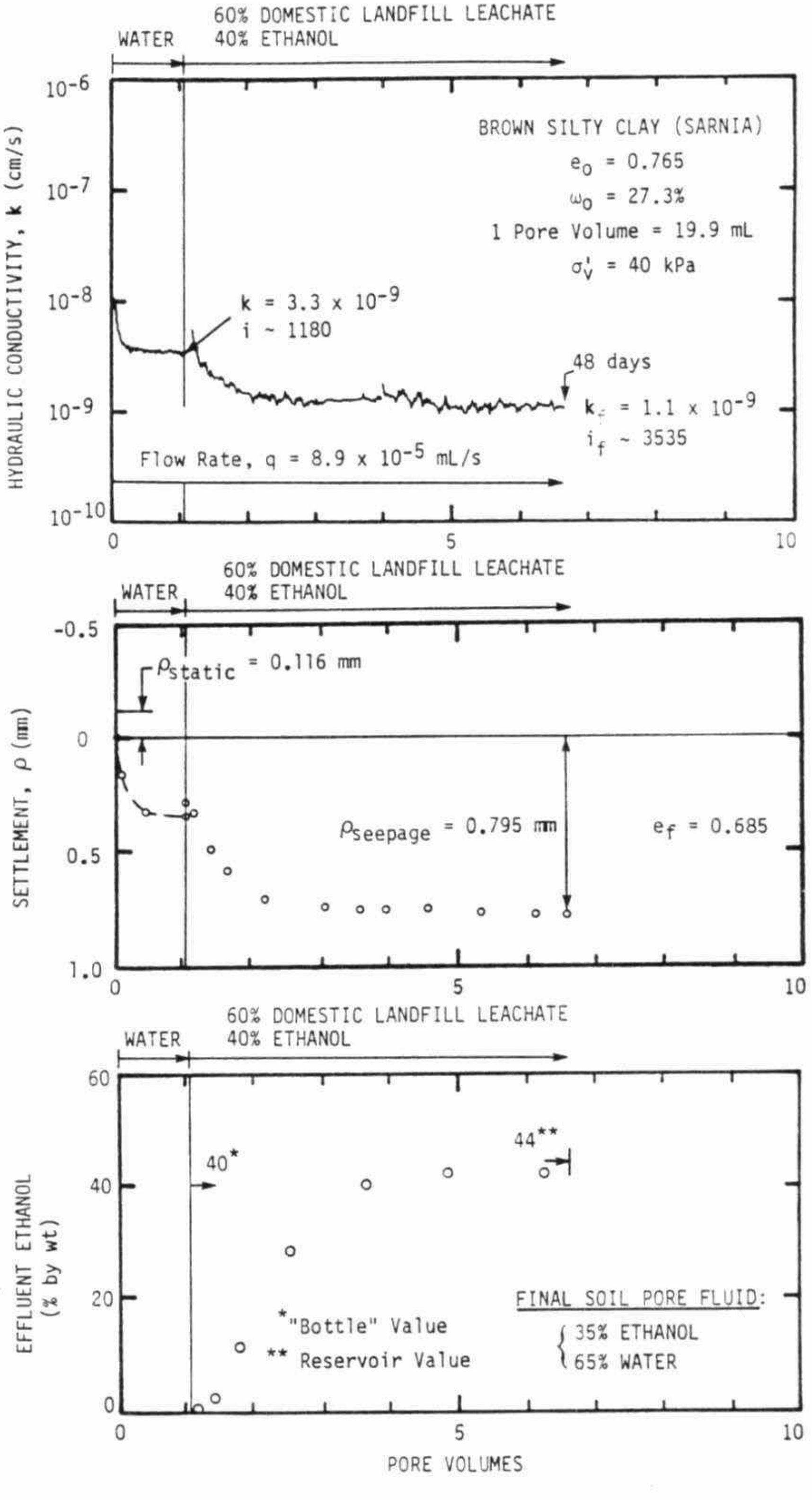

FIGURE E.8 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

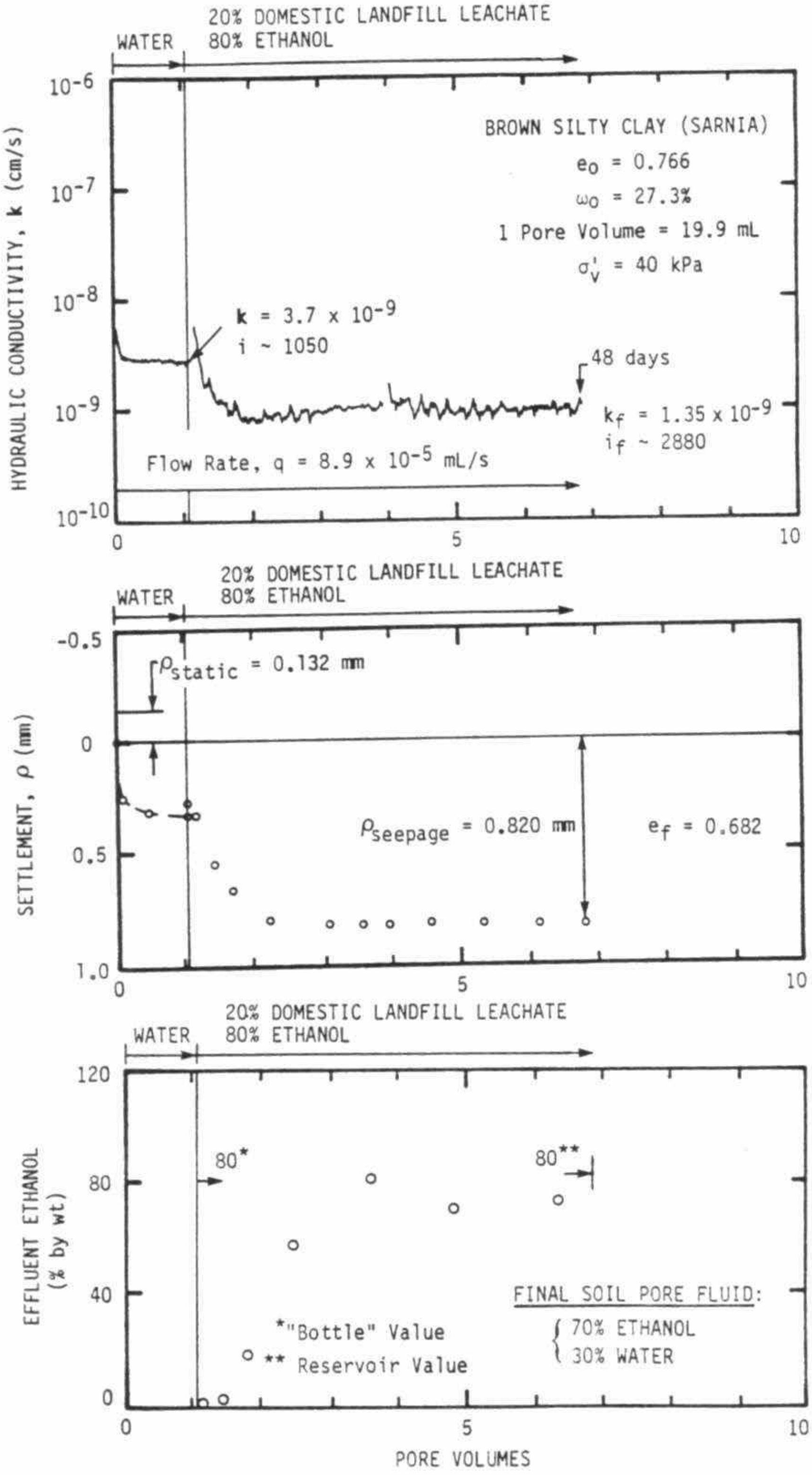

FIGURE E.9 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

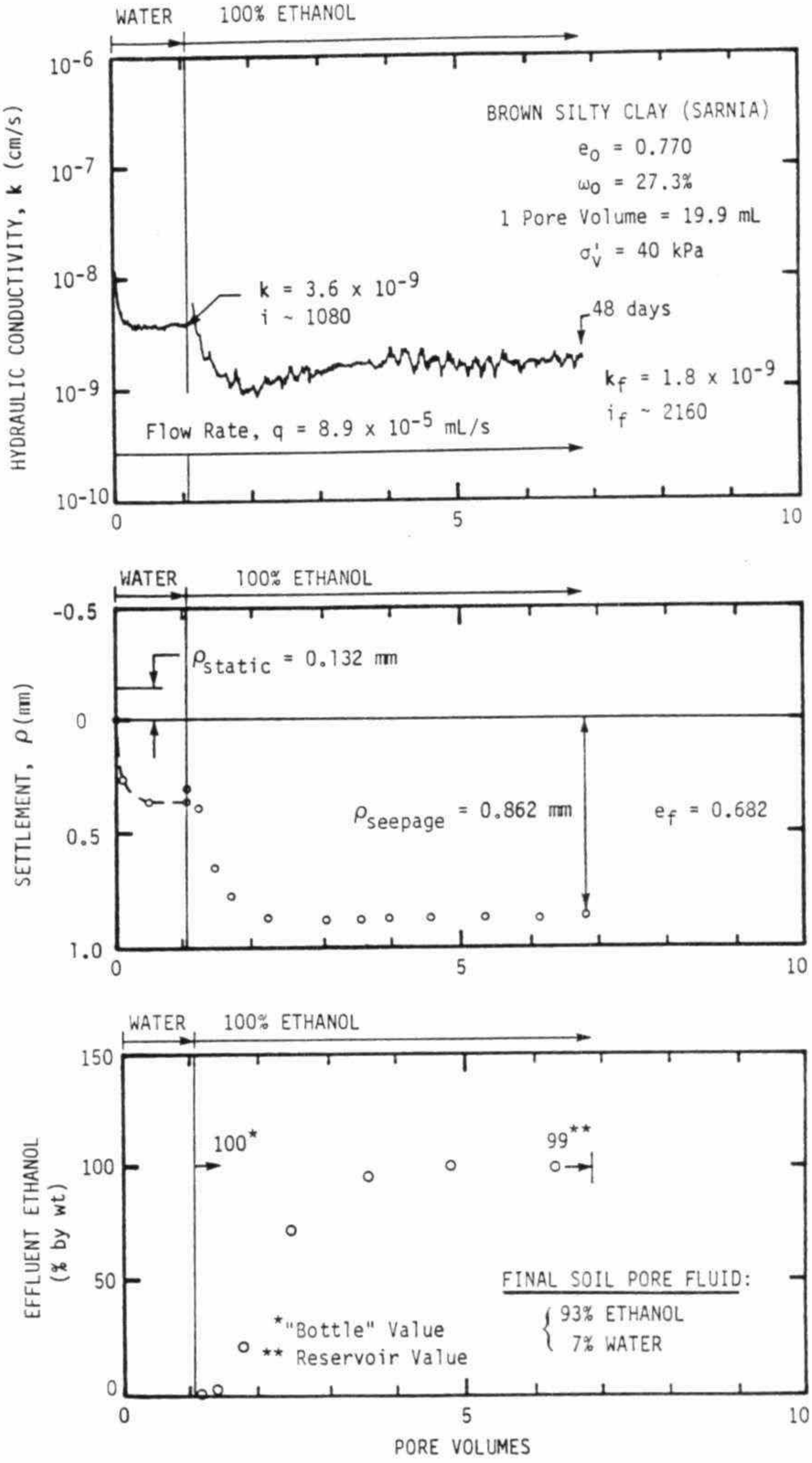

FIGURE E.10 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

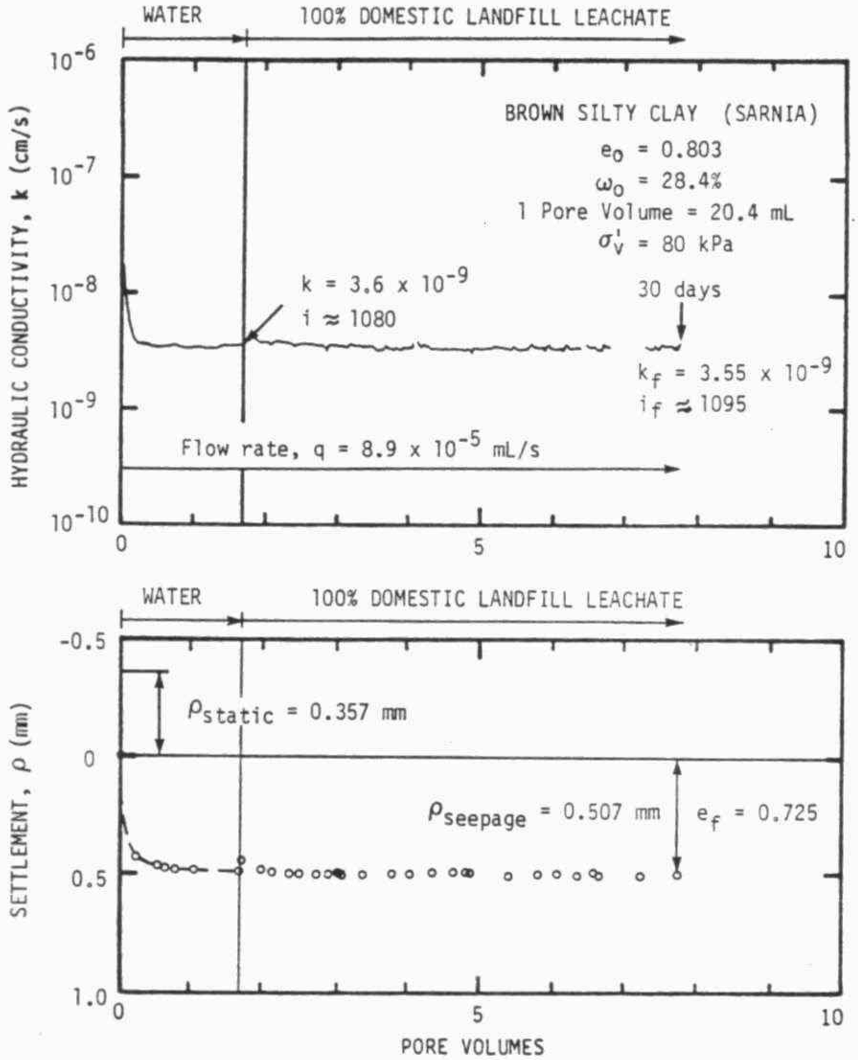

FIGURE E.11 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

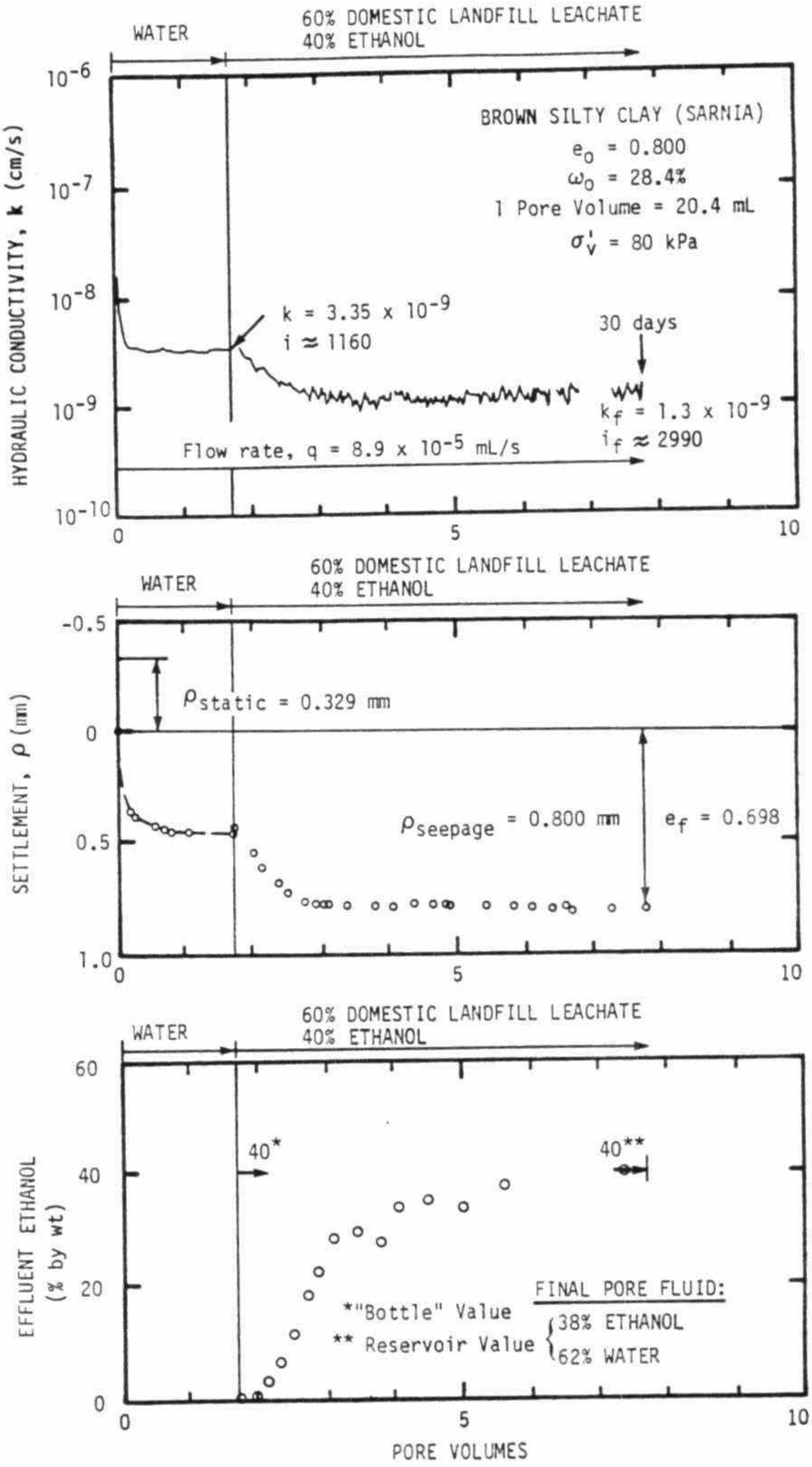

FIGURE E.12 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

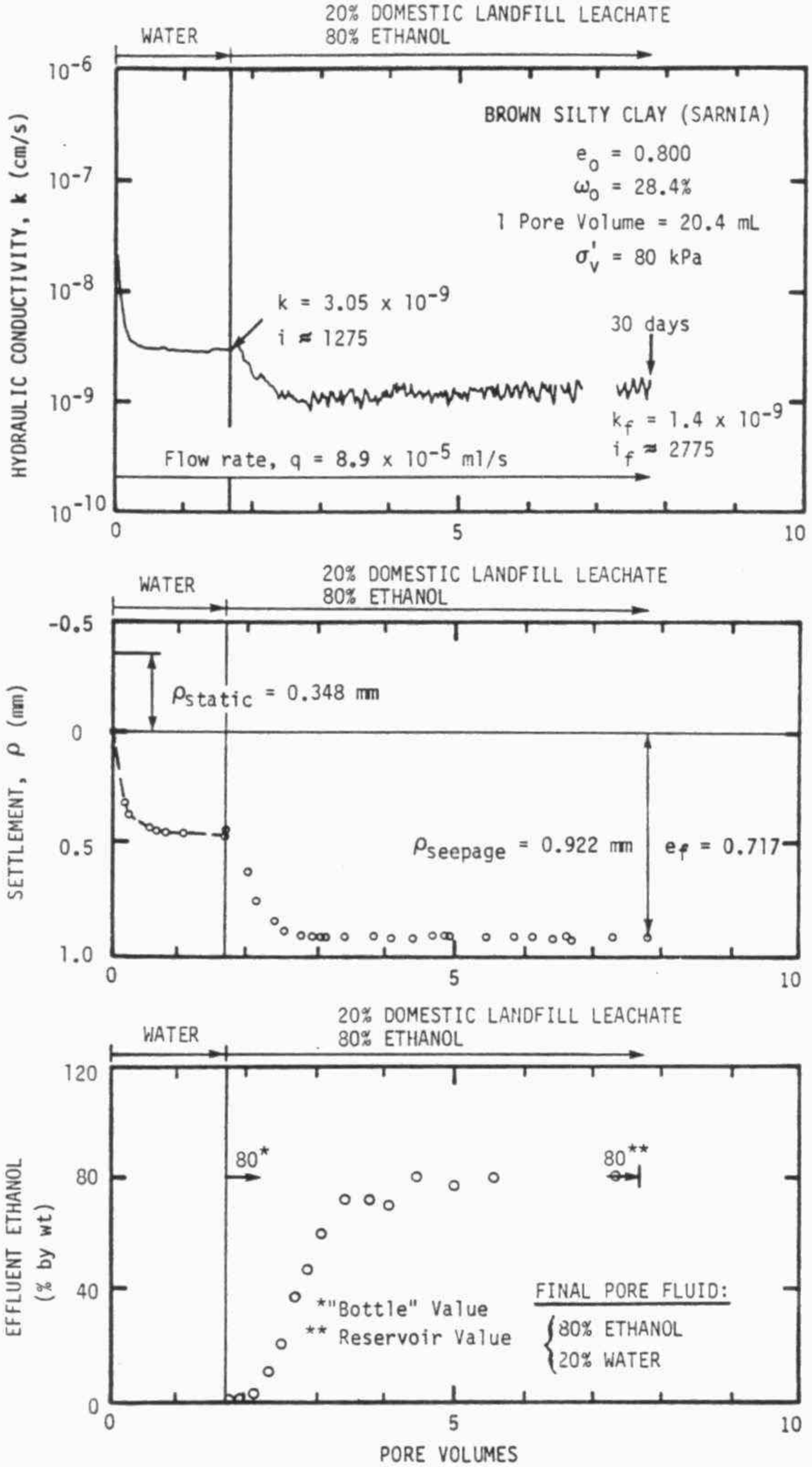

FIGURE E.13 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

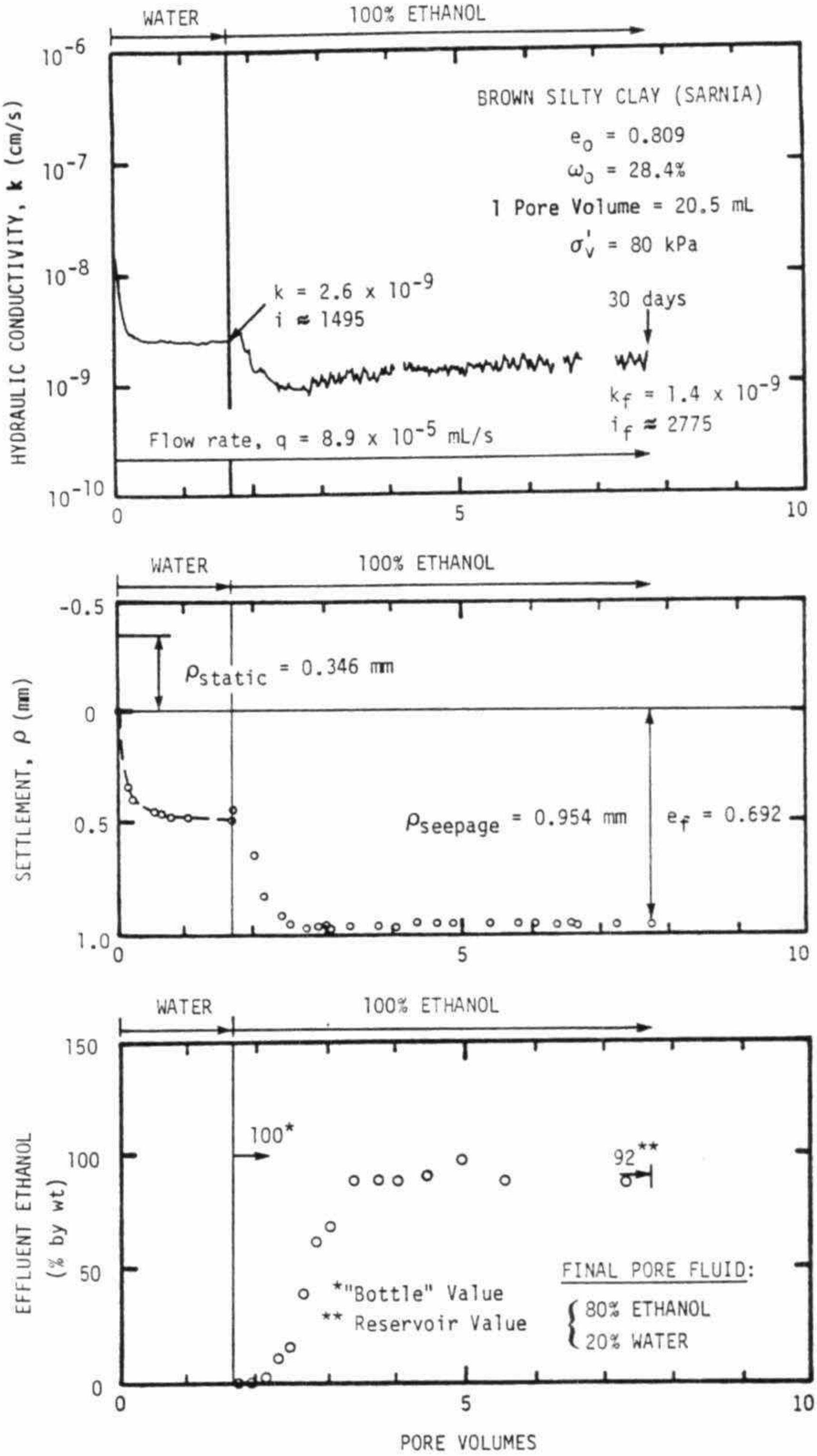

FIGURE E.14 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

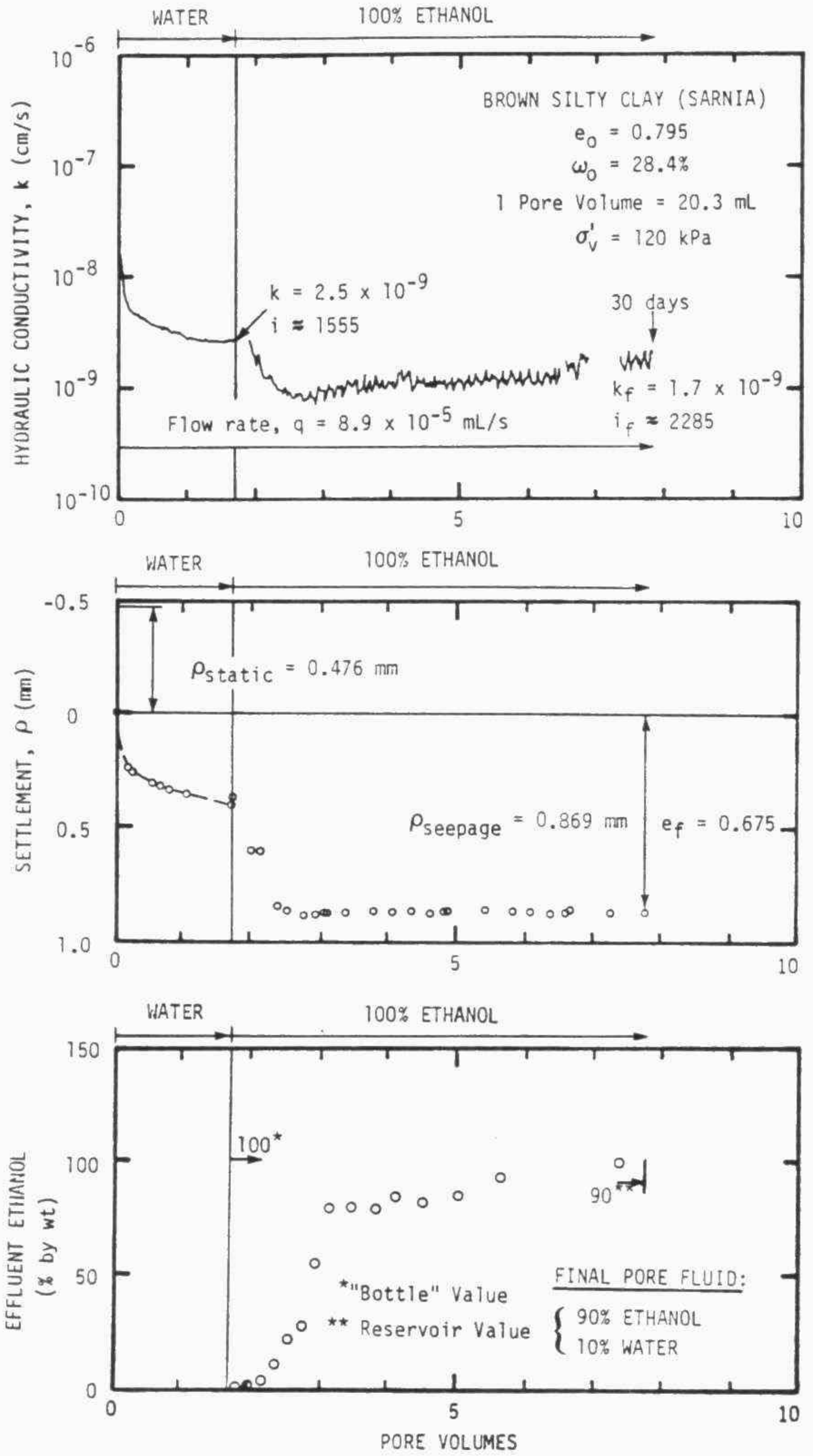

FIGURE E.15 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

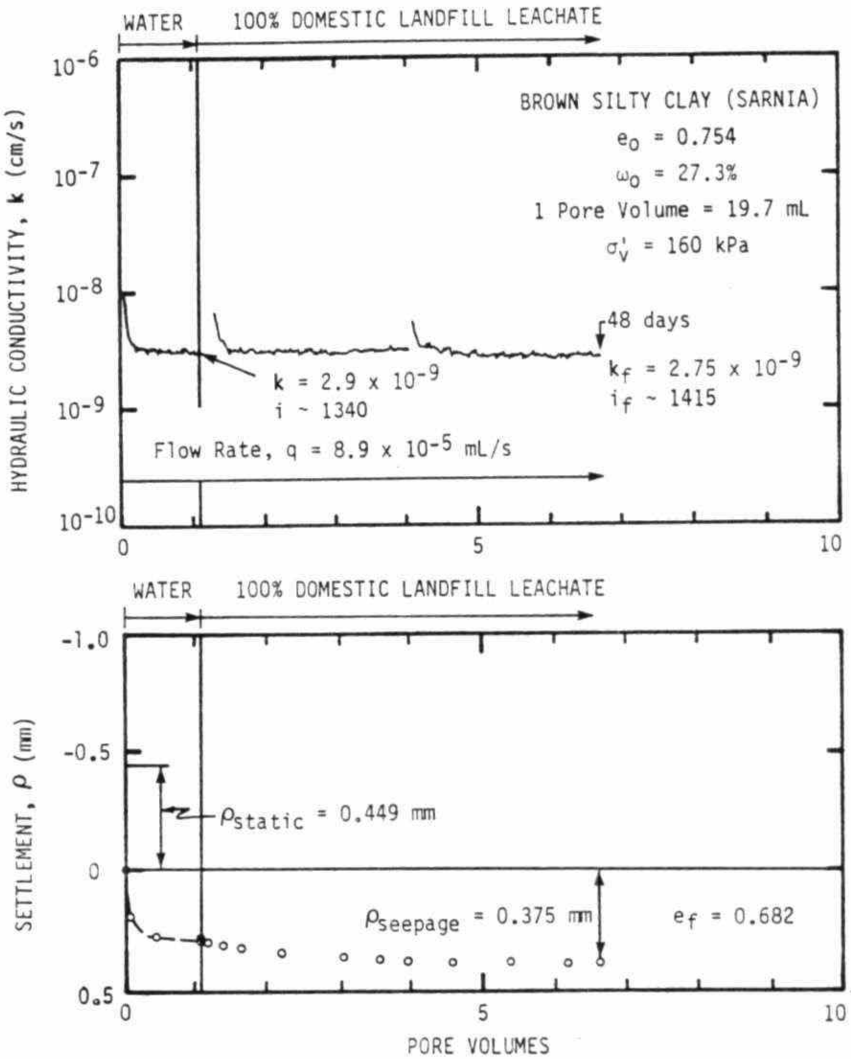

FIGURE E.16 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

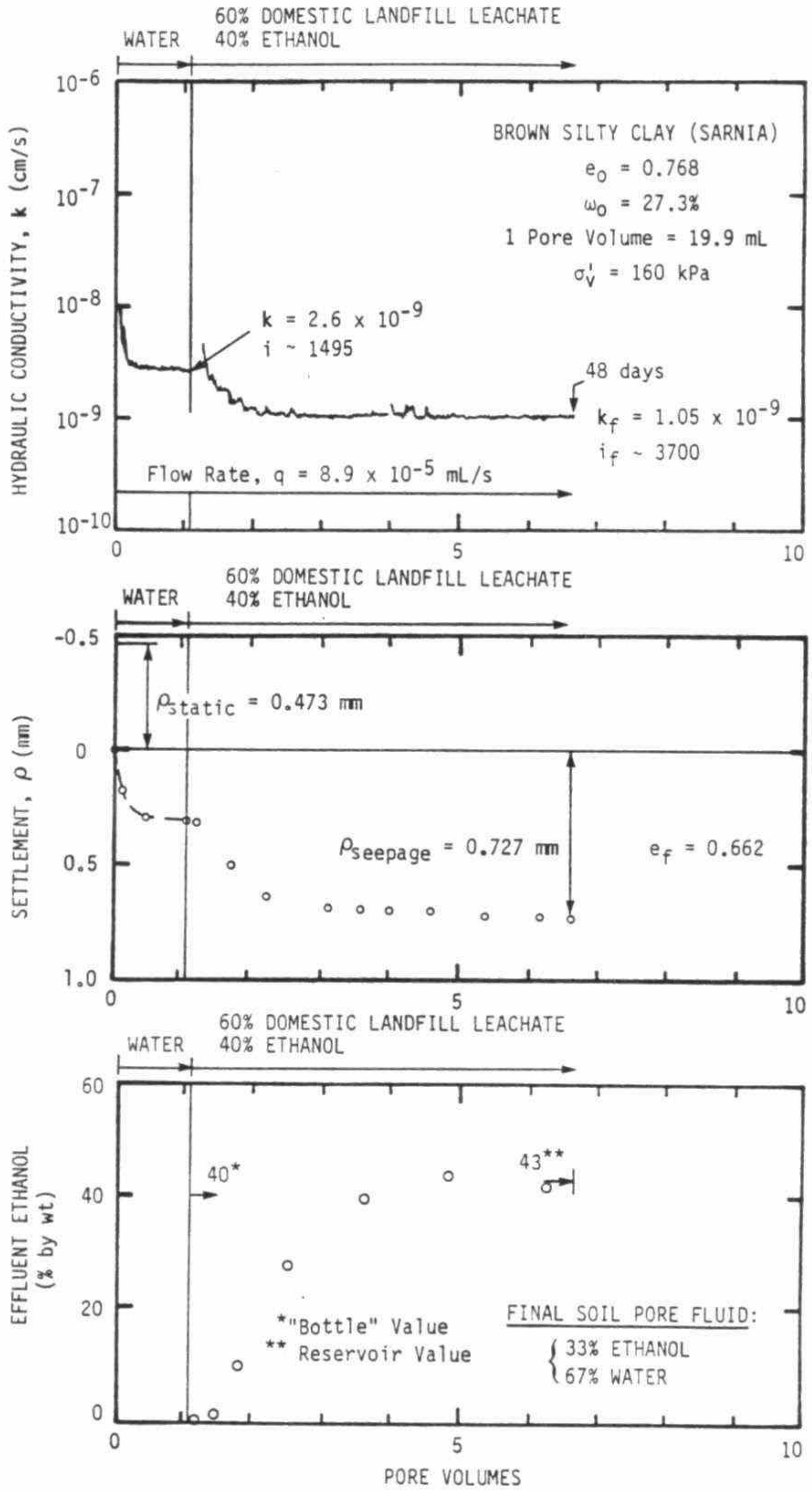

FIGURE E.17 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

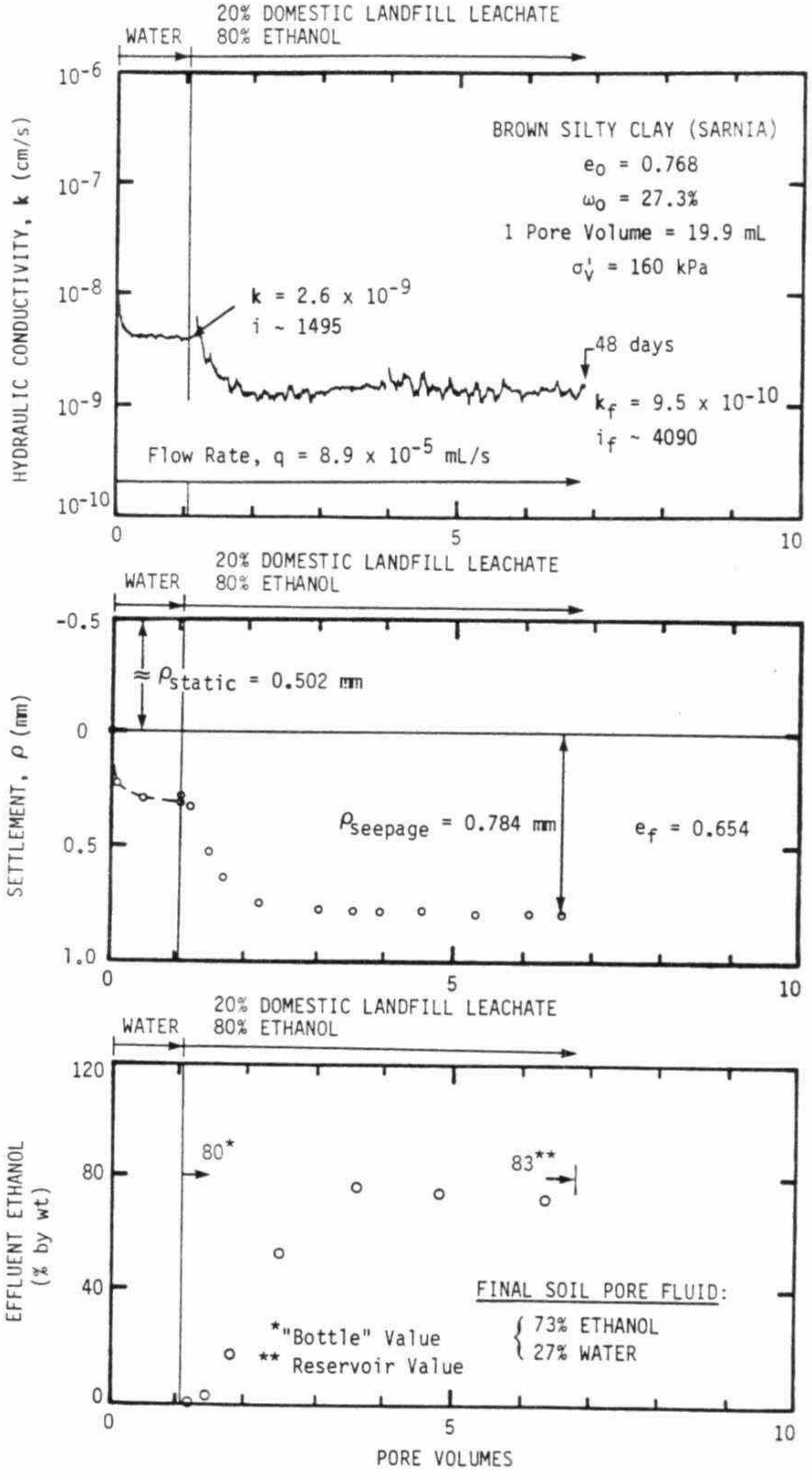

FIGURE E.18 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

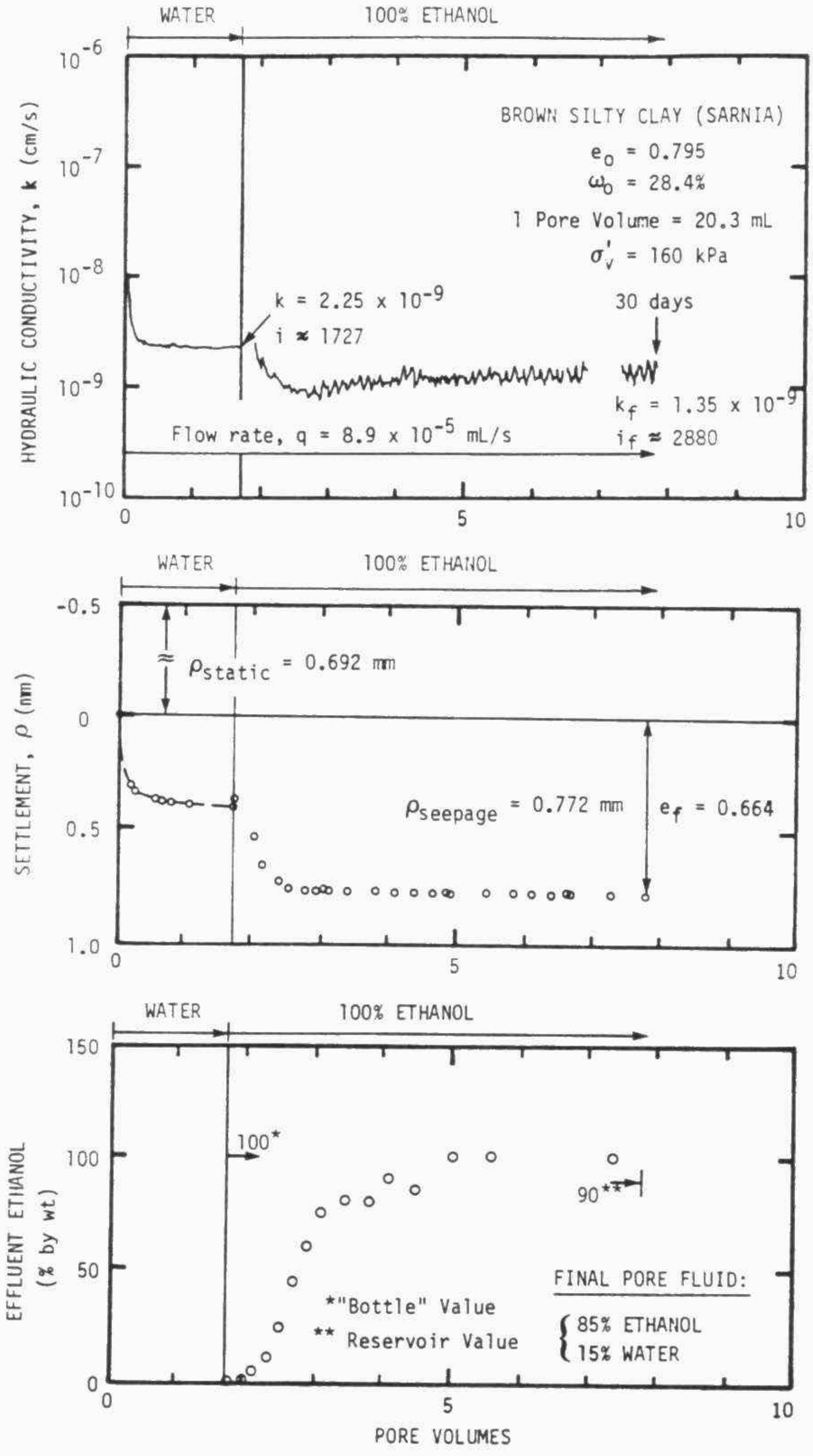

FIGURE E.19 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

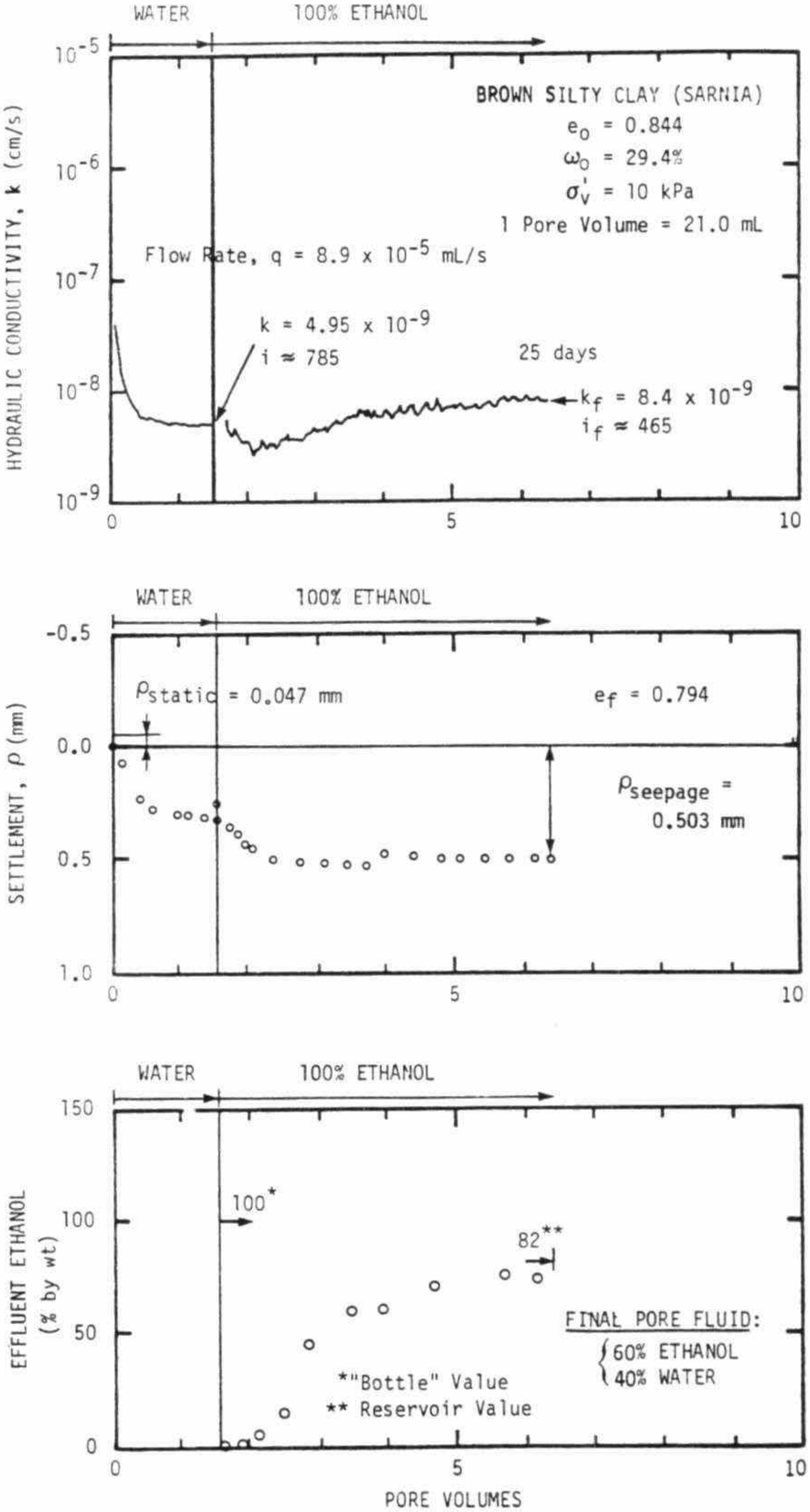

FIGURE E.20 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

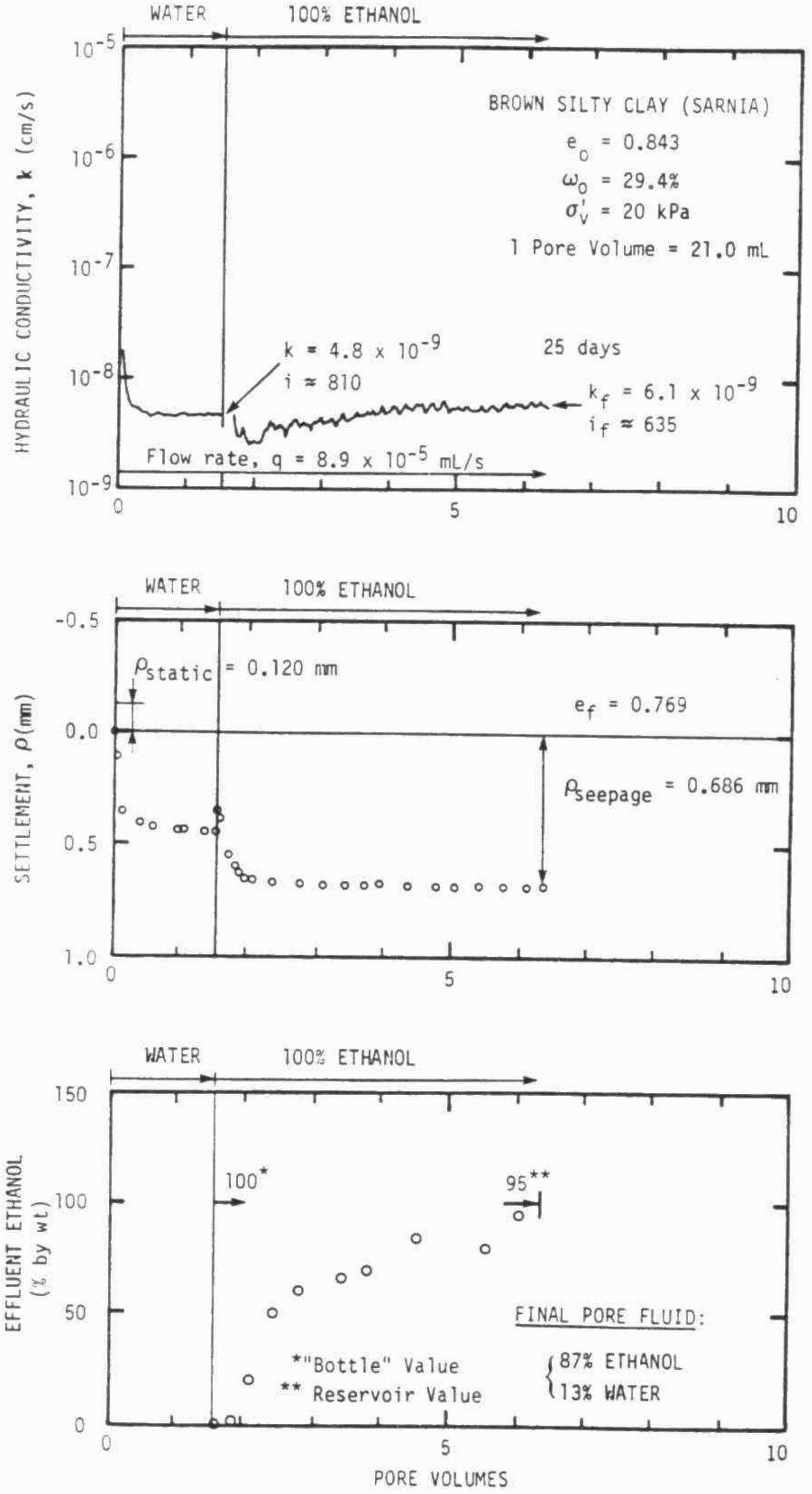

FIGURE E.21 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

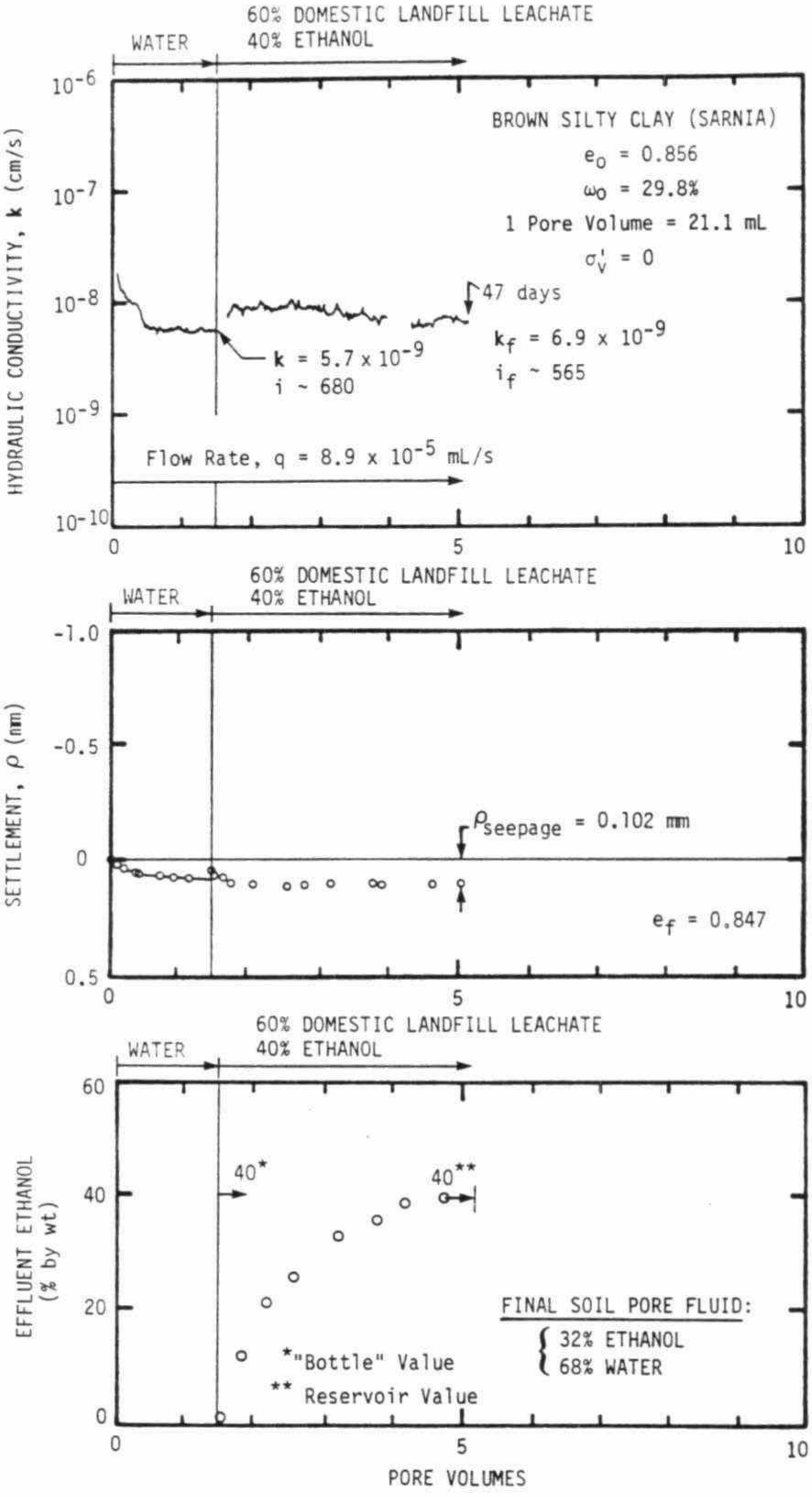

FIGURE E.22 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

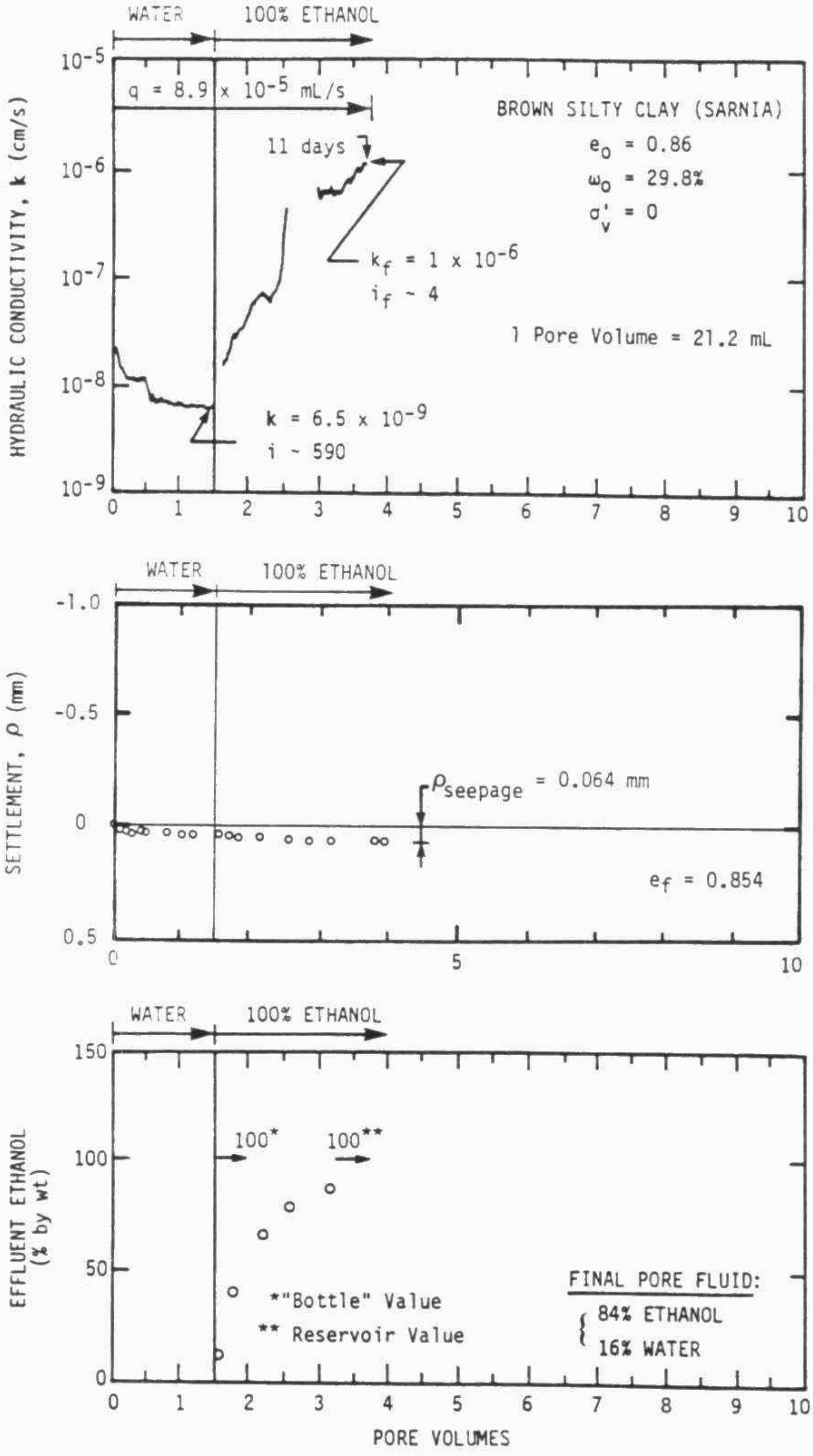

FIGURE E.23 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

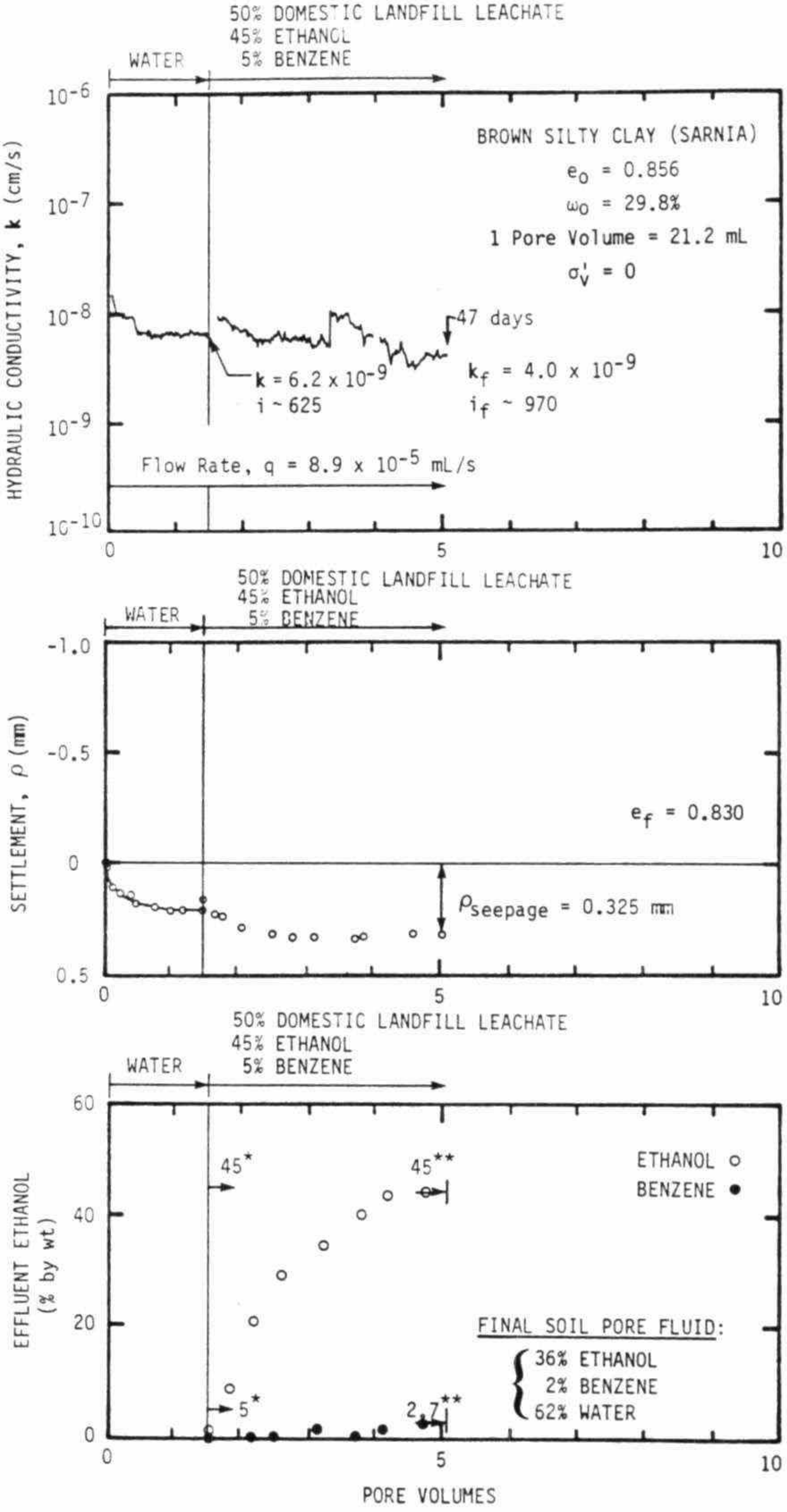

FIGURE E.24 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

APPENDIX F

HYDRAULIC CONDUCTIVITY CURVES FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH LEACHATE/DIOXANE MIXTURES

This figures presented in this appendix describe the results of hydraulic conductivity, settlement and effluent composition for tests performed on water-compacted brown Sarnia clays permeated with leachate/dioxane mixtures at the following static effective stresses: σ'_v = 0 kPa (Figures F.1 to F.6), σ'_v = 40 kPa (Figures F.7 to F.9), σ'_v = 80 kPa (Figures F.10 to F.12), σ'_v = 120 kPa (Figure F.13) and σ'_v = 160 kPa (Figures F.14 to F.16).

The test results are discussed in Section 5.3.2 of this report.

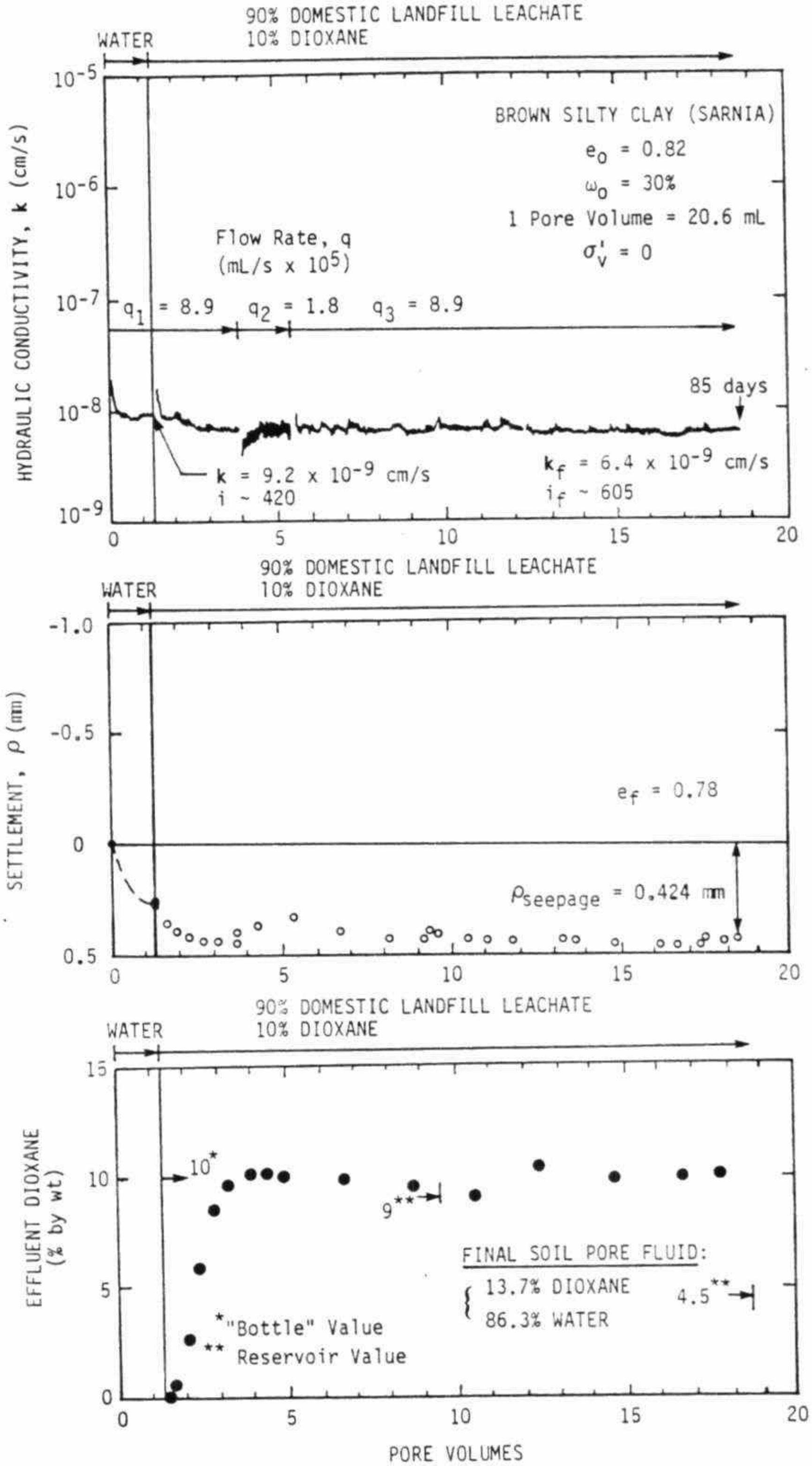

FIGURE F.1 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

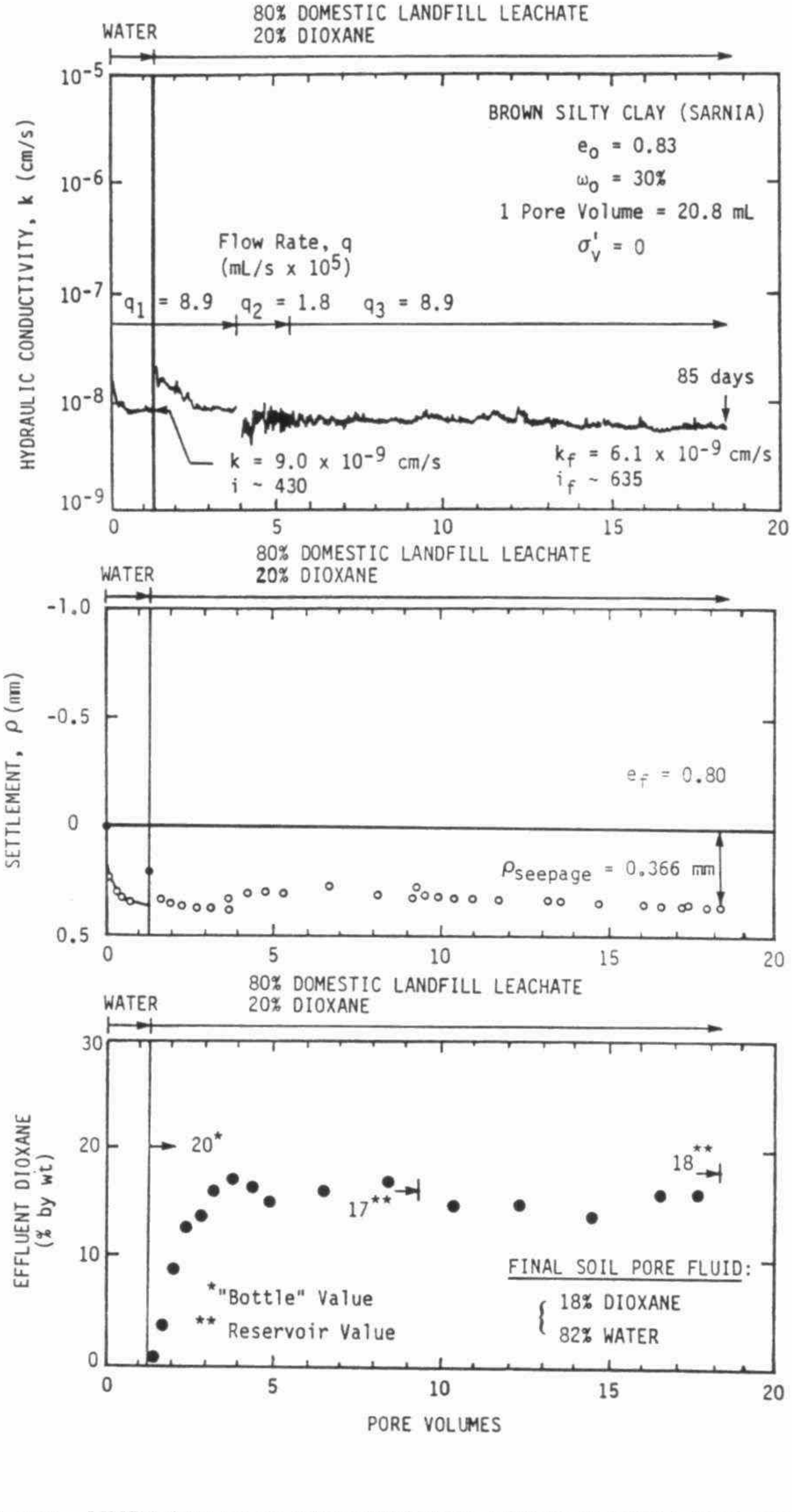

FIGURE F.2 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

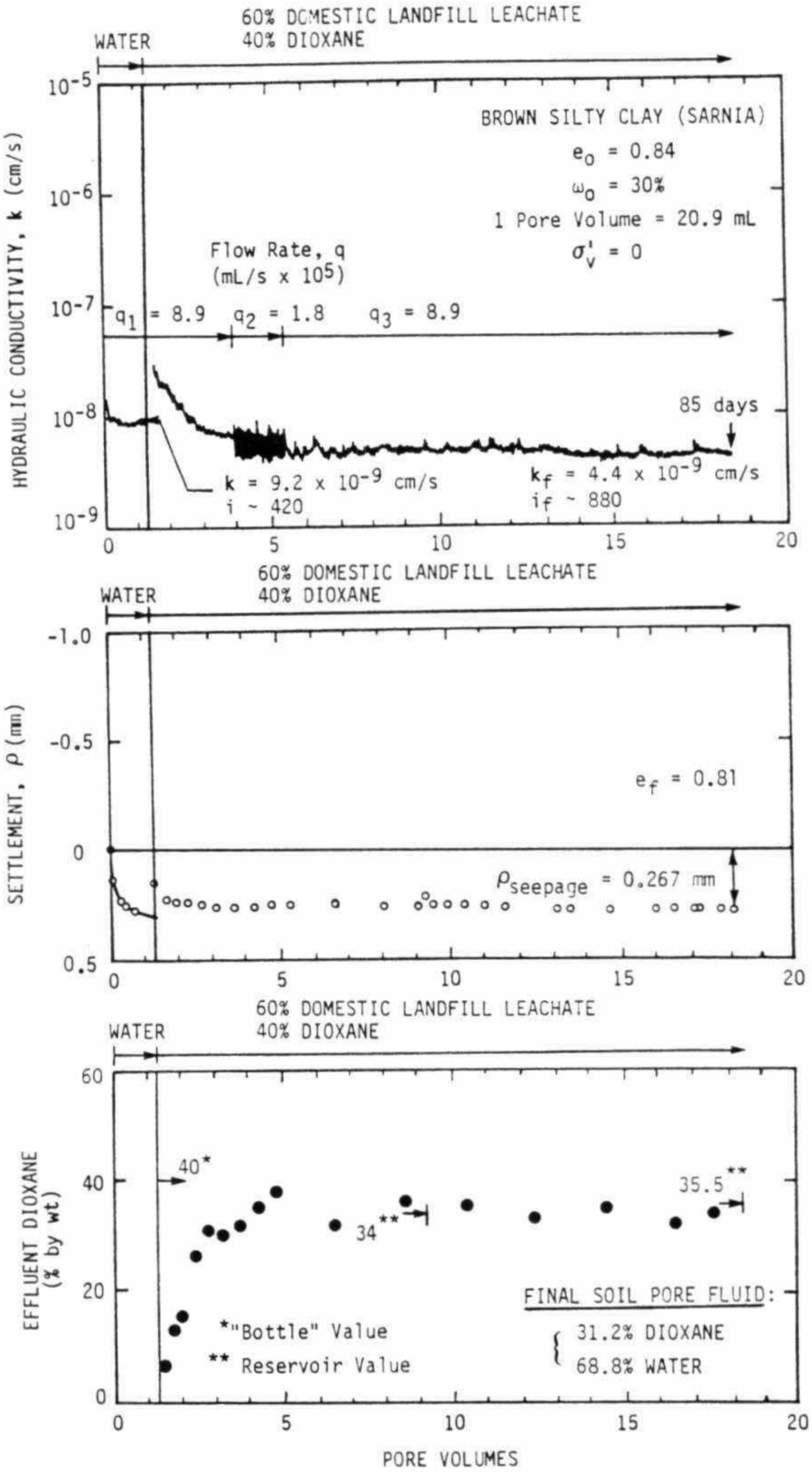

FIGURE F.3 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

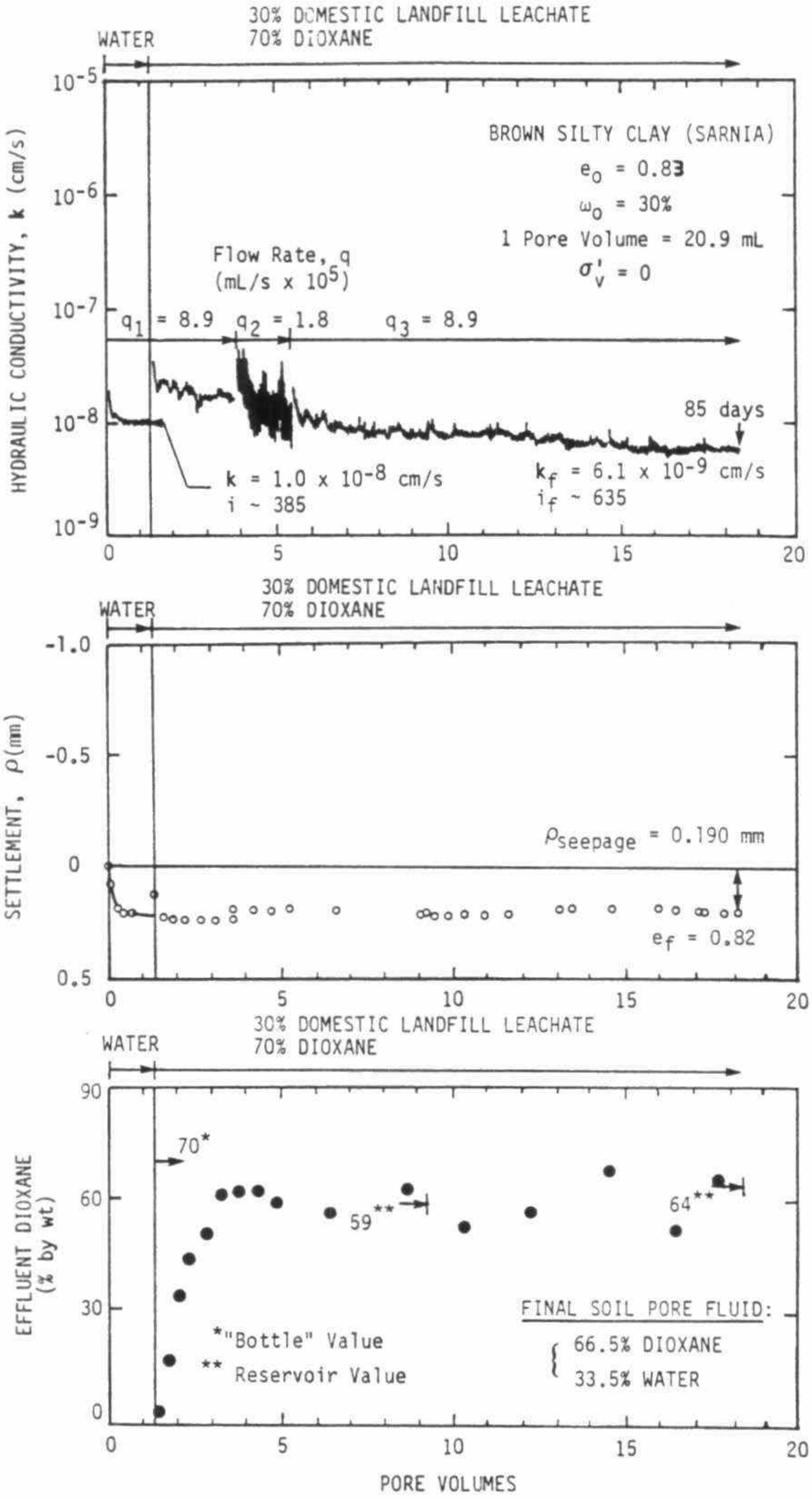

FIGURE F.4 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

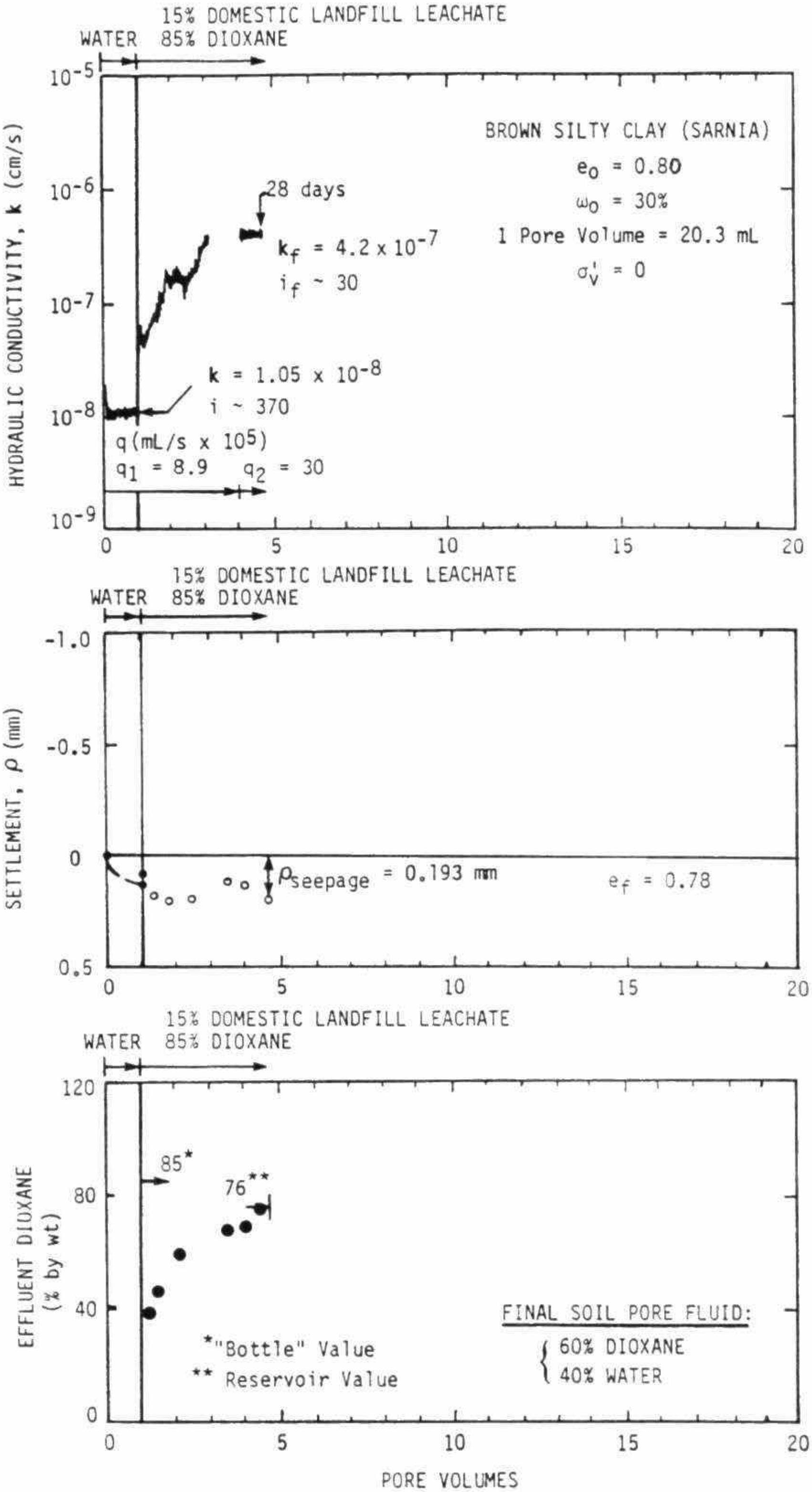

FIGURE F.5 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

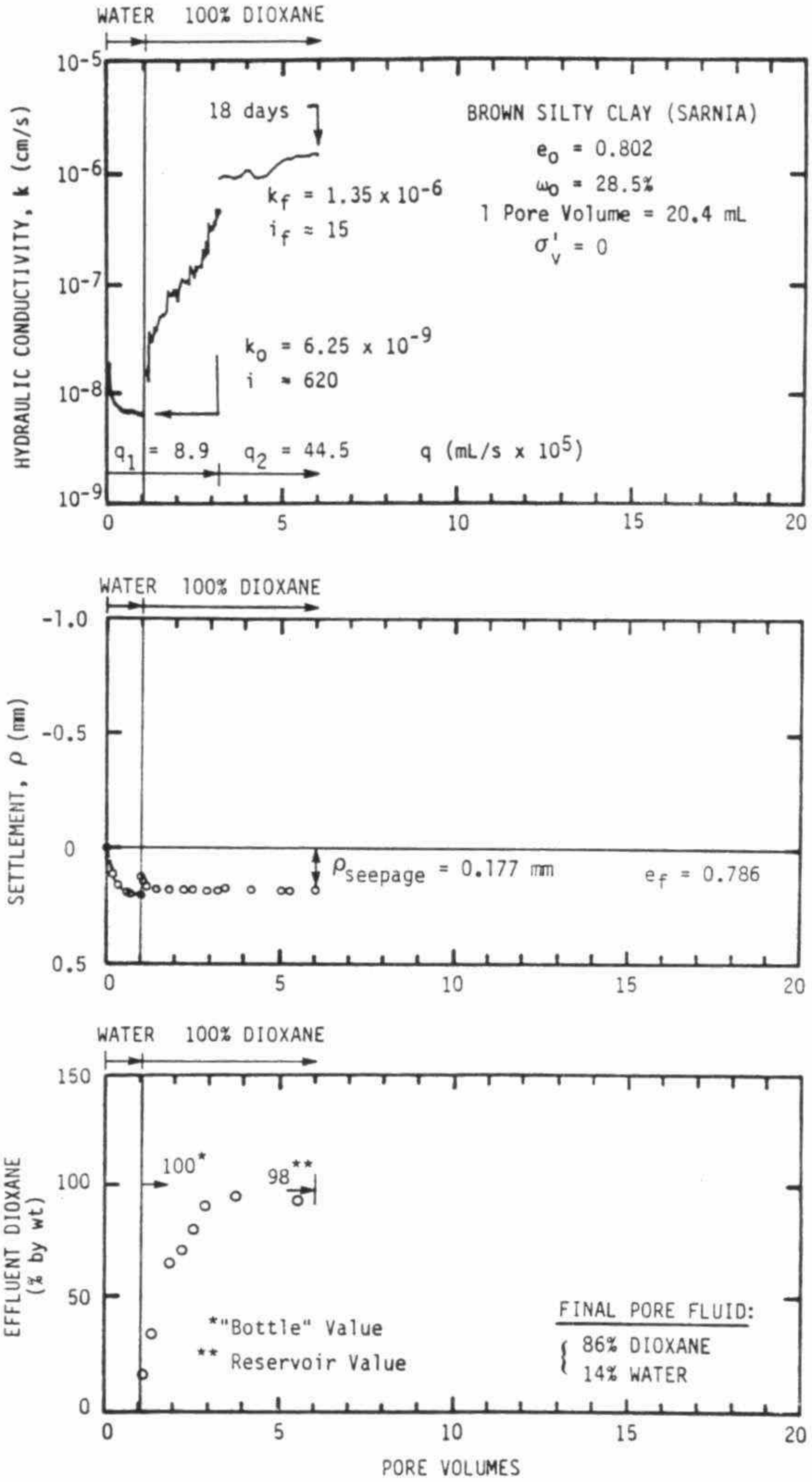

FIGURE F.6 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

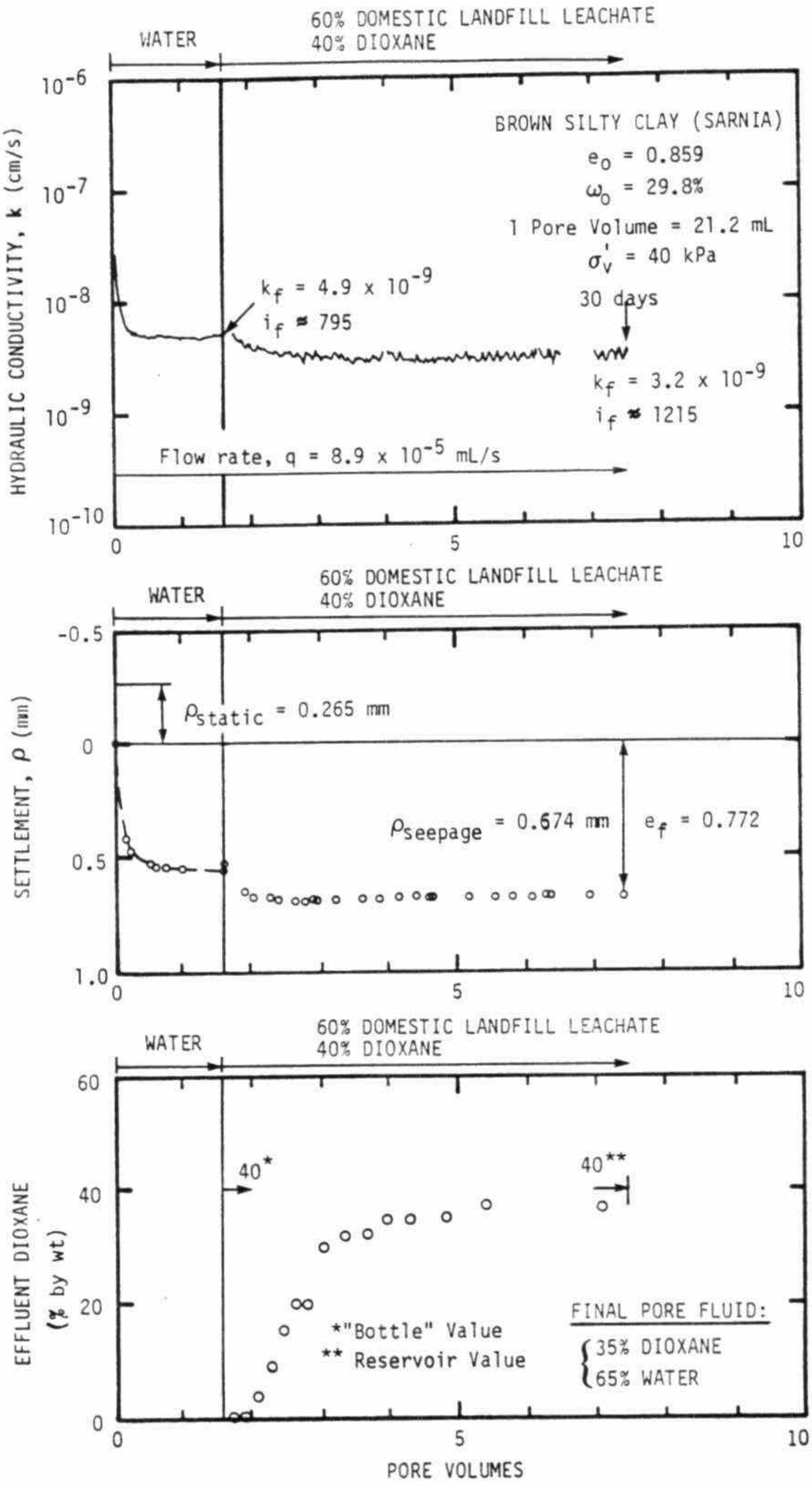

FIGURE F.7 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

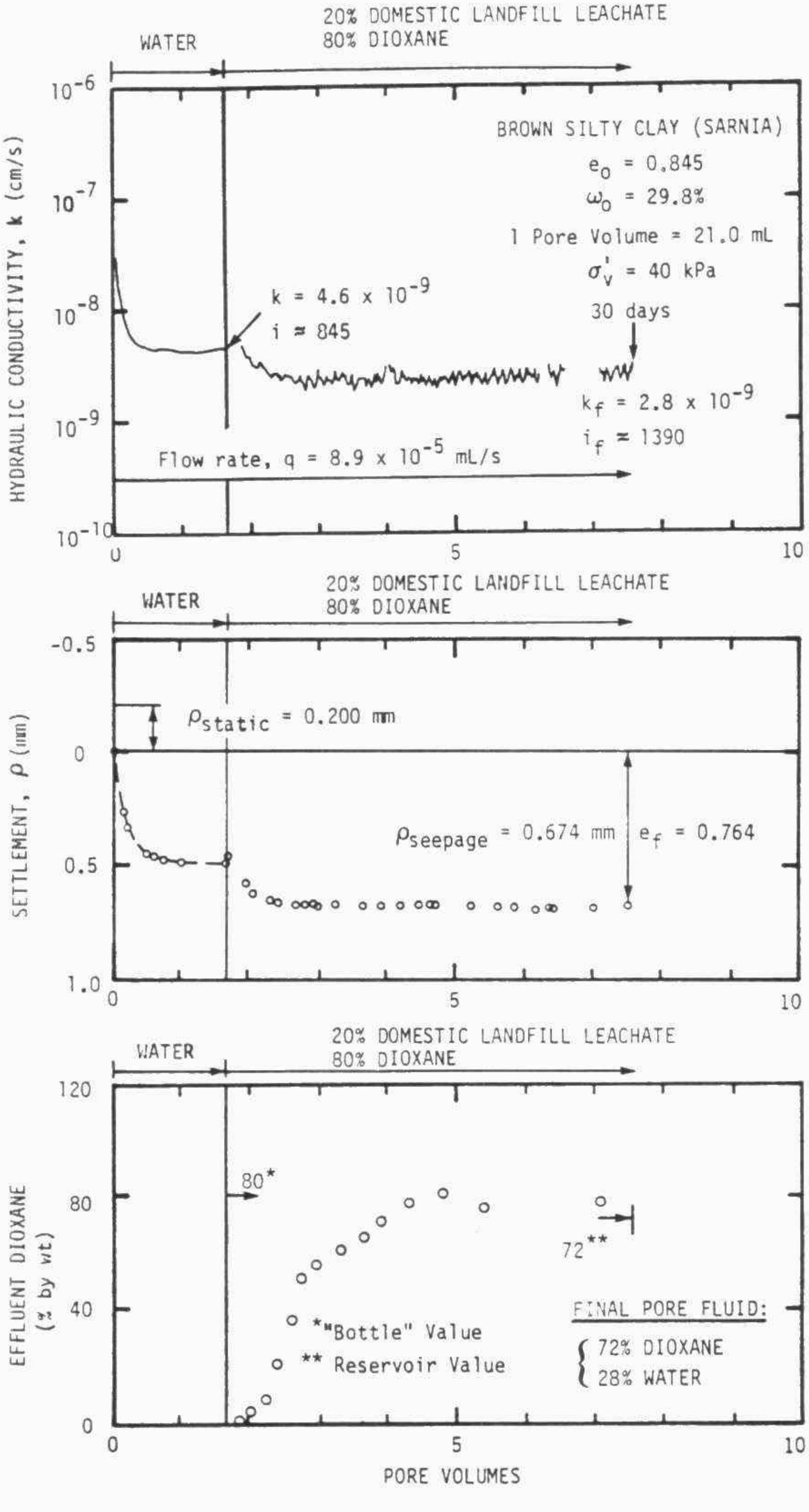

FIGURE F.8 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

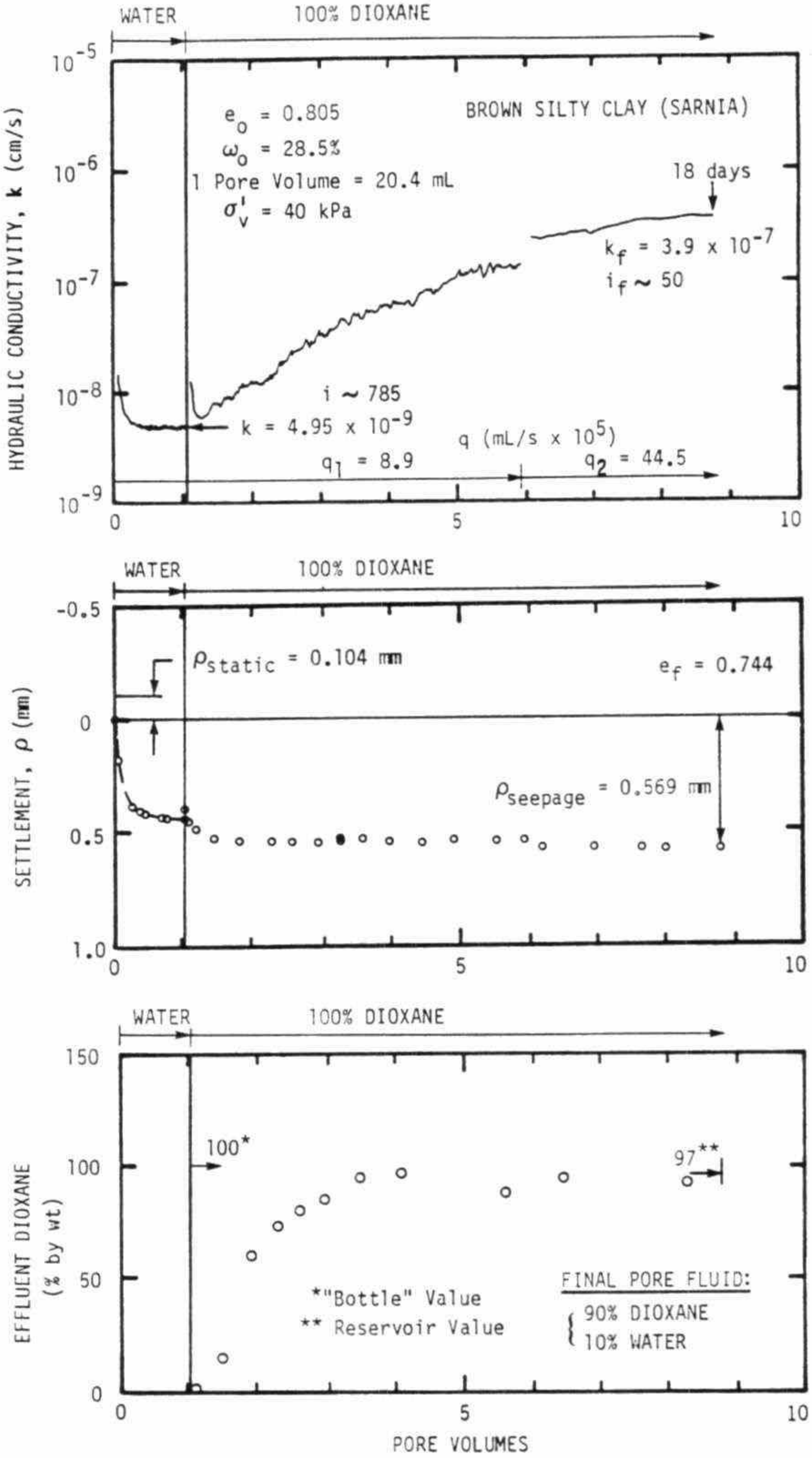

FIGURE F.9 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

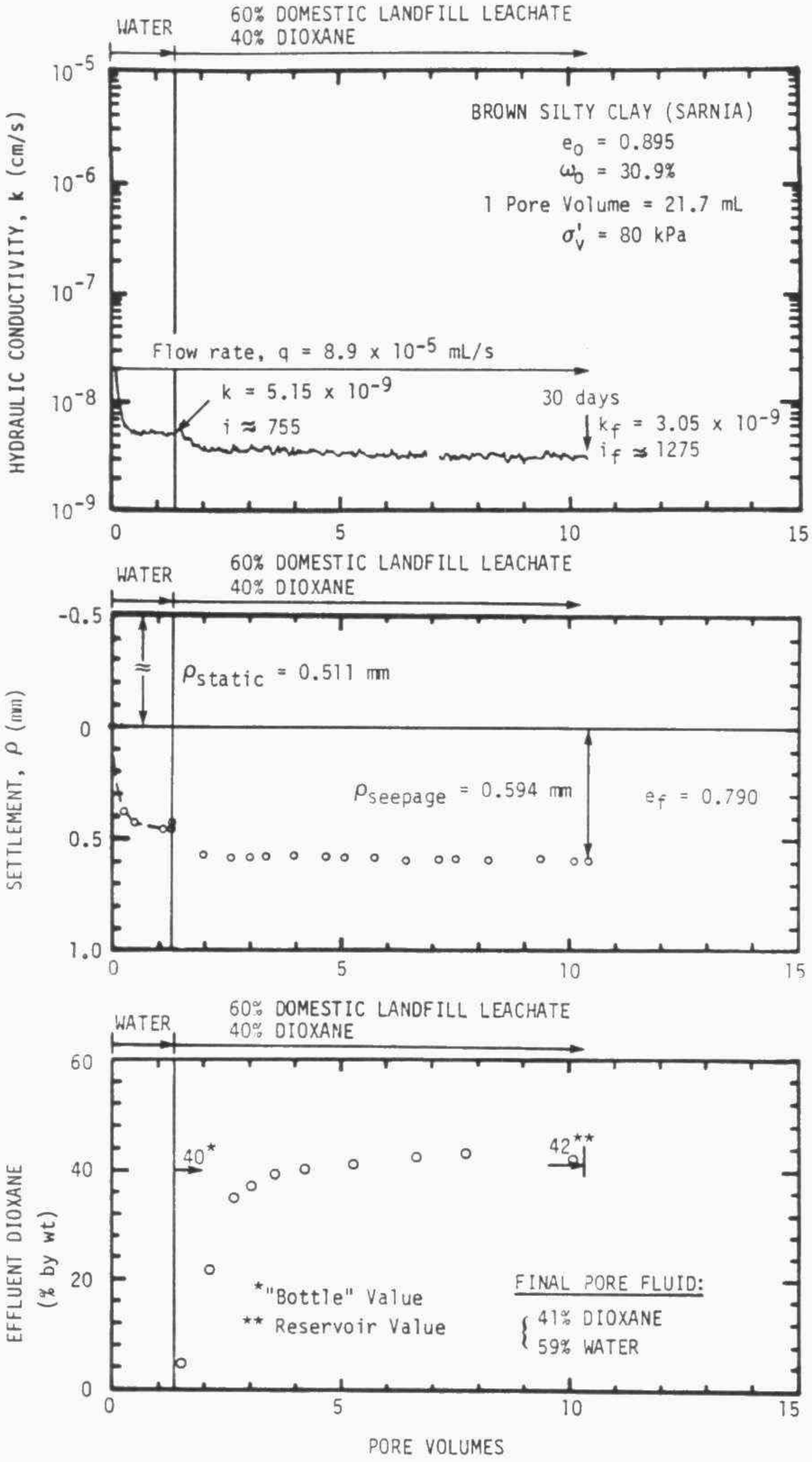

FIGURE F.10 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

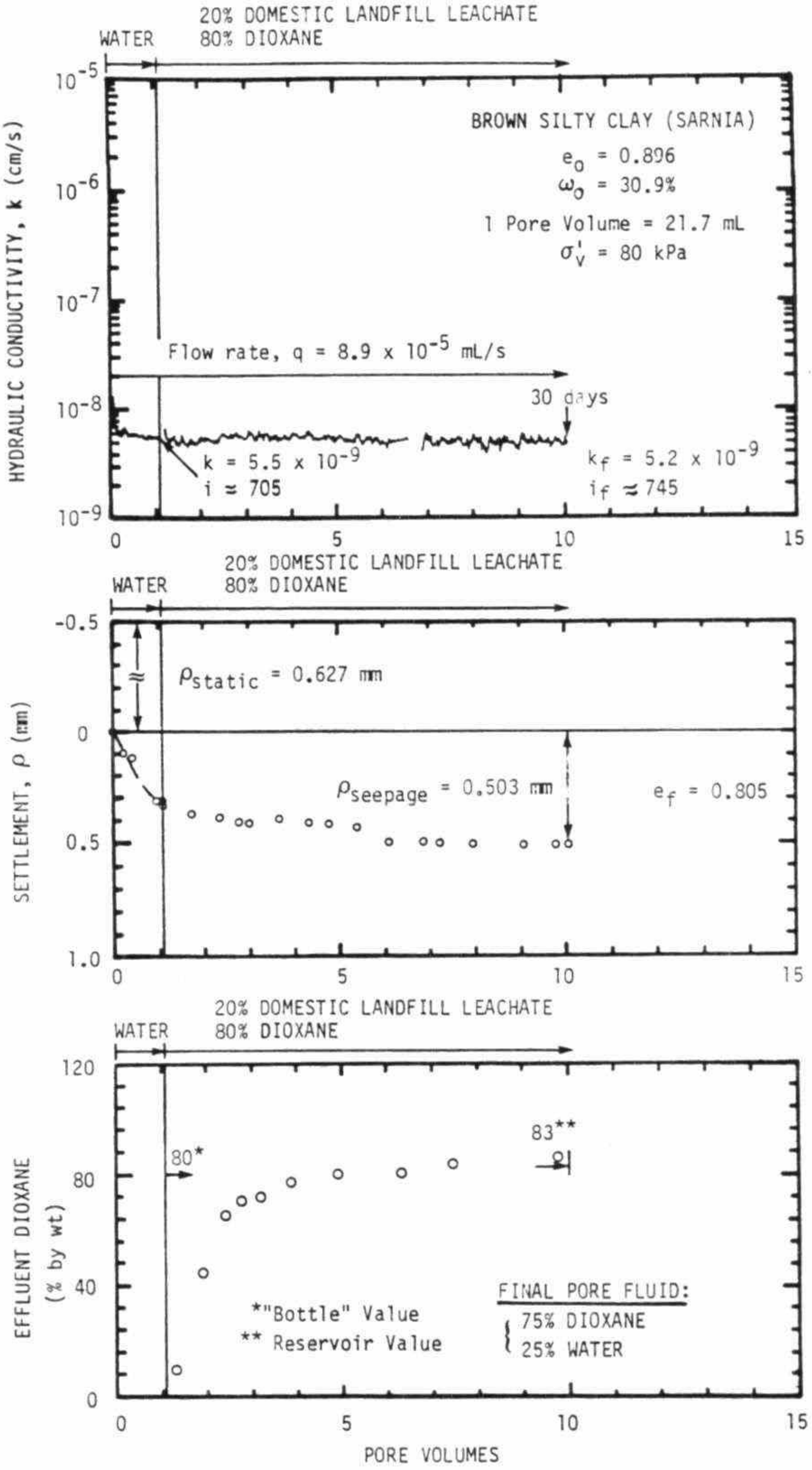

FIGURE F.11 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

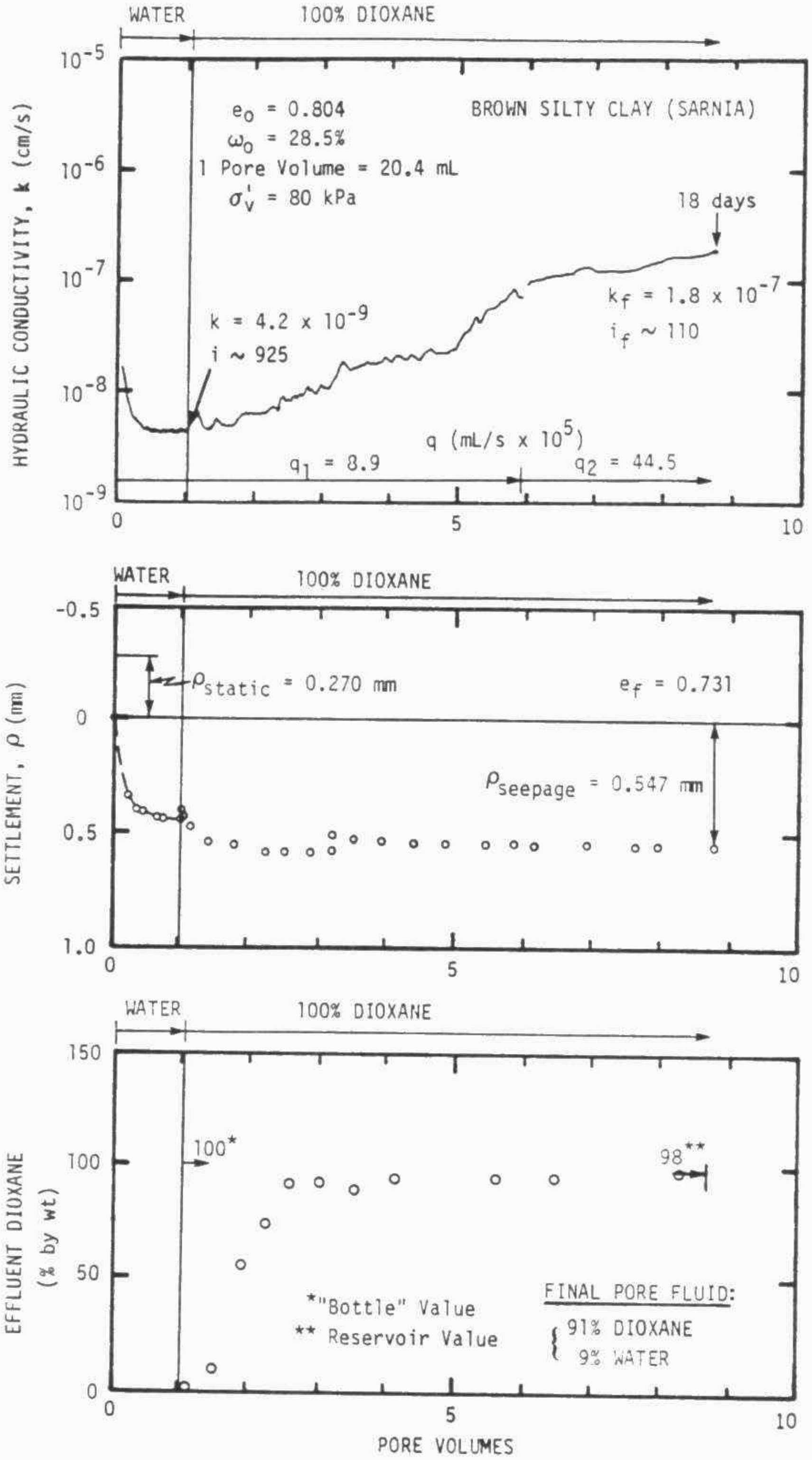

FIGURE F.12 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

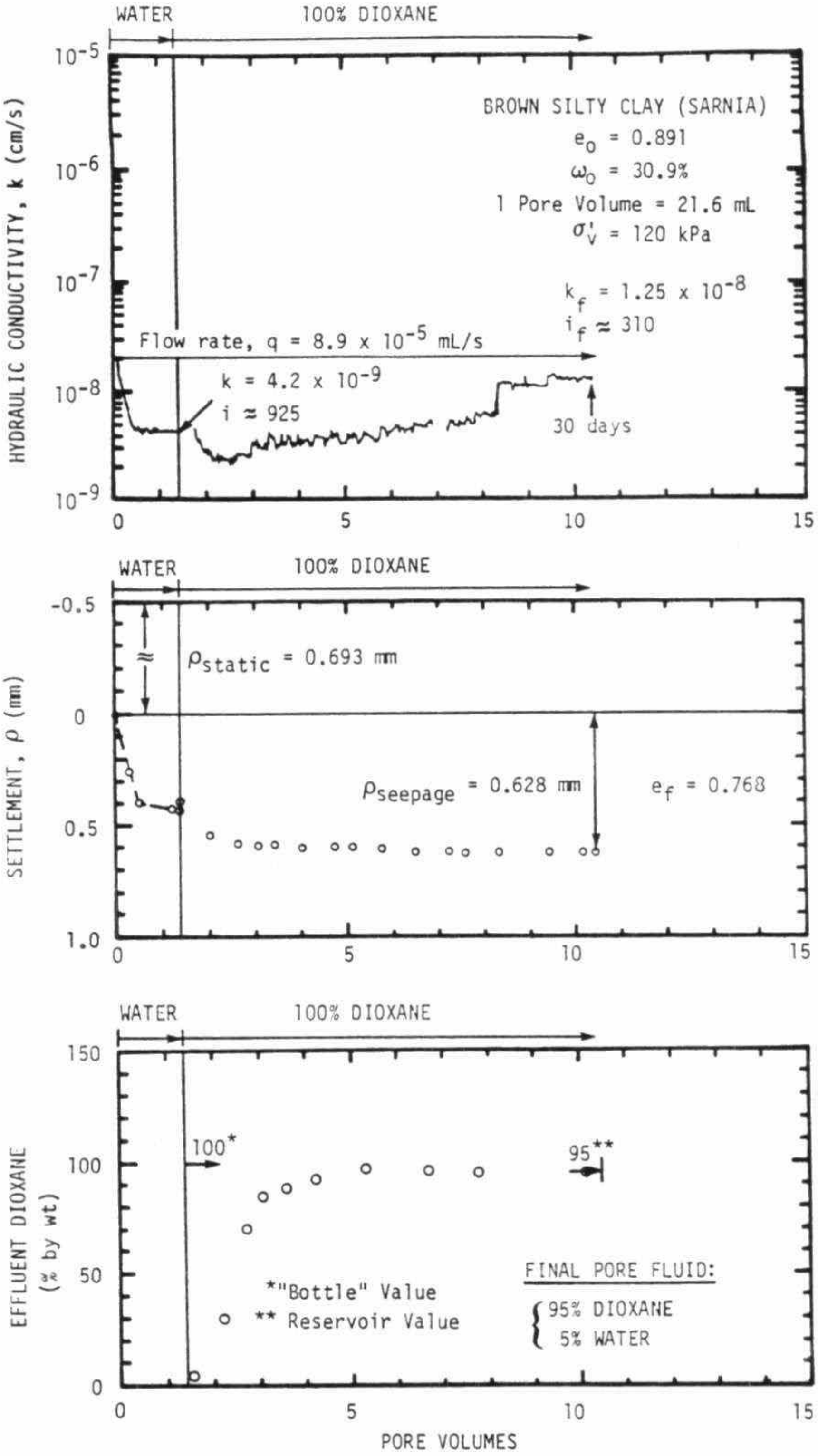

FIGURE F.13 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

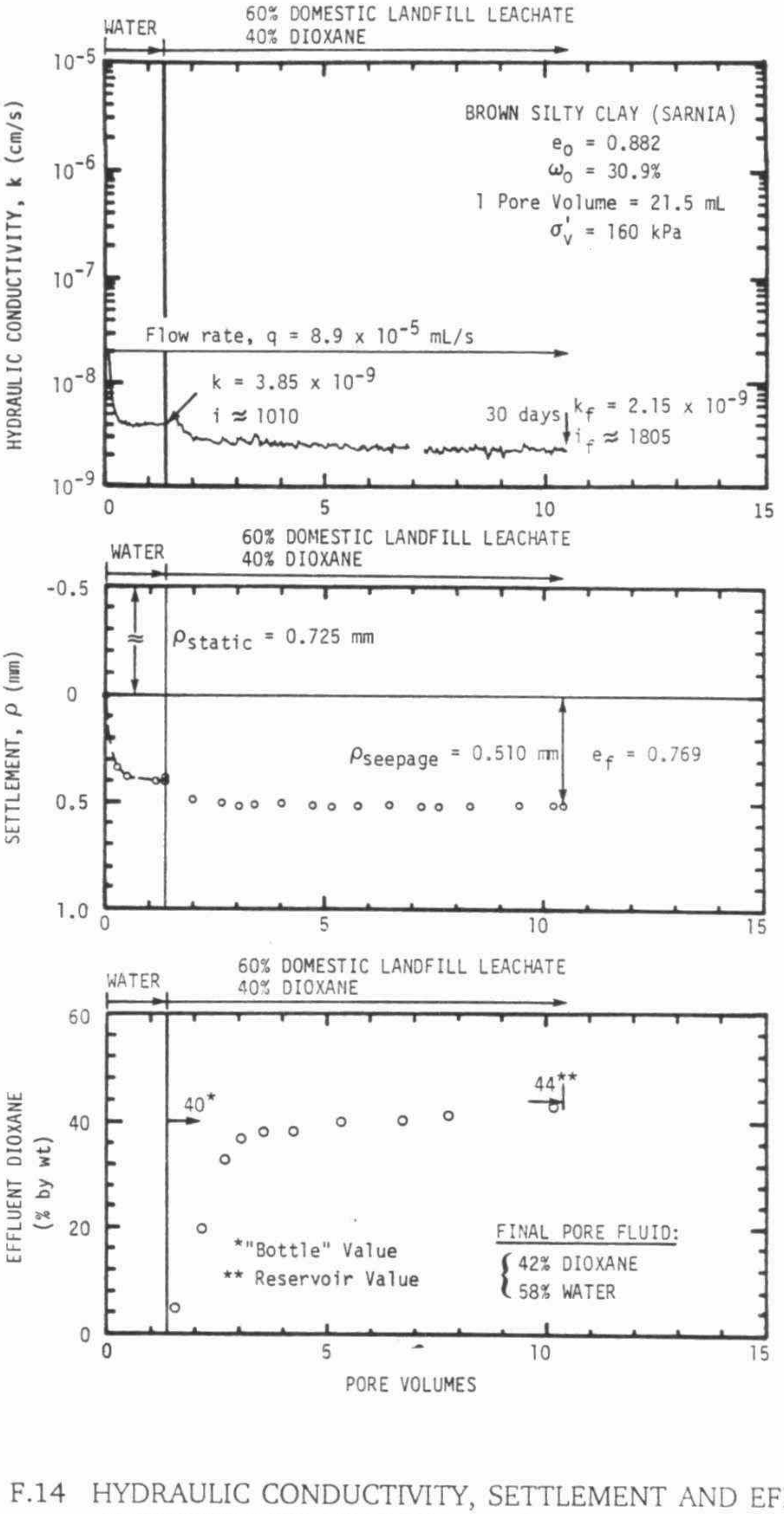

FIGURE F.14 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

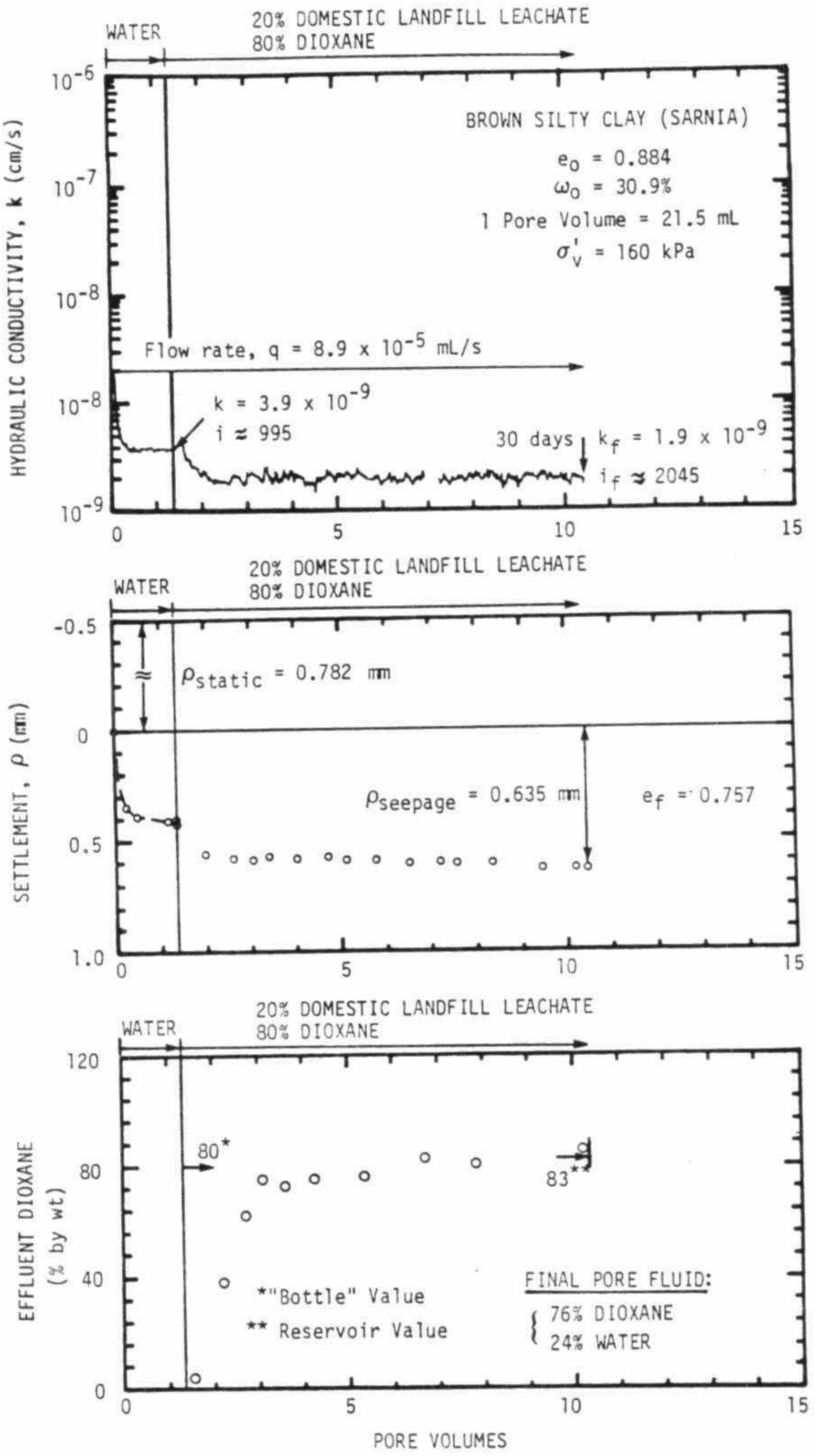

FIGURE F.15 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

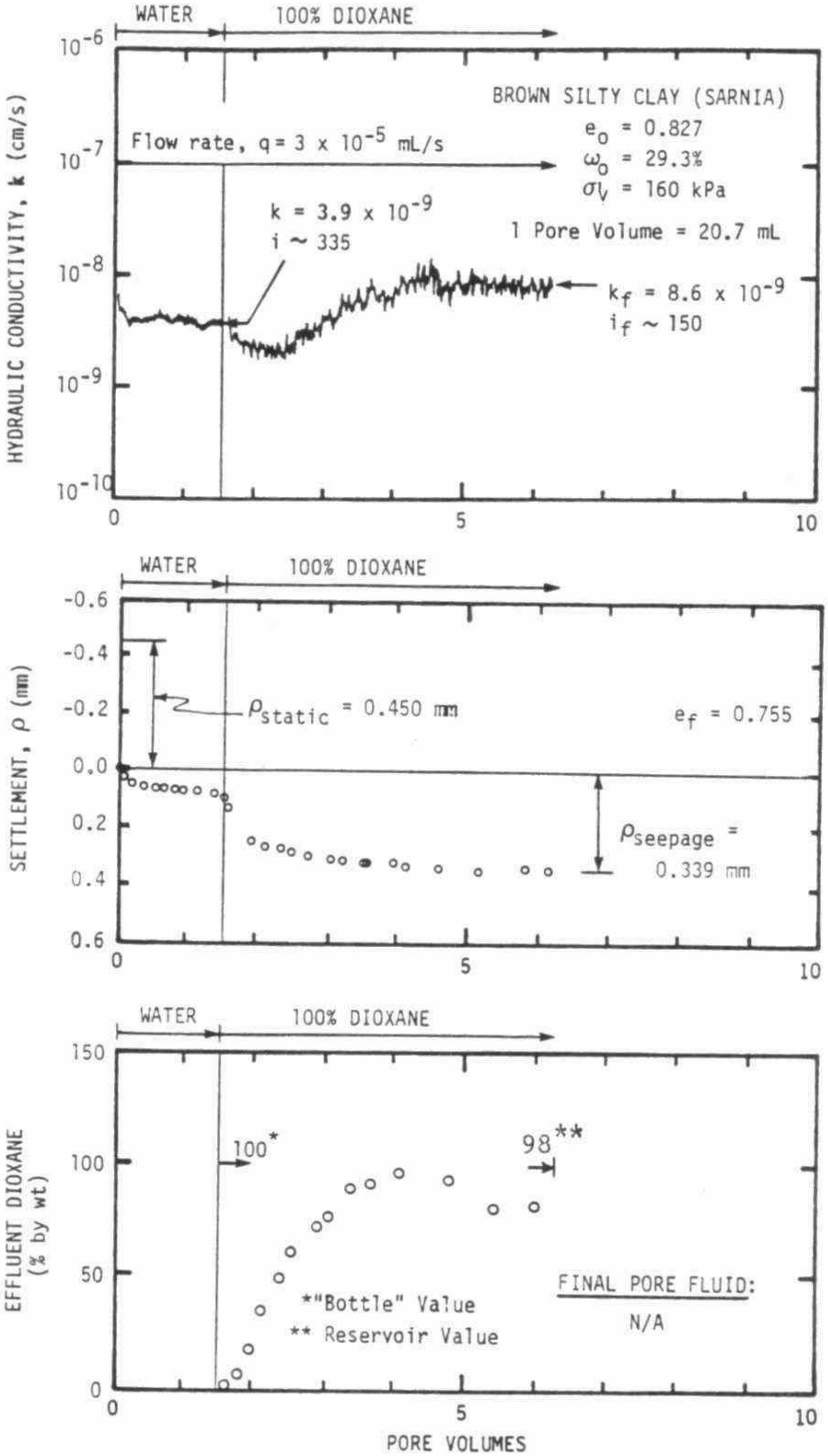

FIGURE F.16 HYDRAULIC CONDUCTIVITY, SETTLEMENT AND EFFLUENT CHEMISTRY VS PORE VOLUMES

APPENDIX G

HYDRAULIC CONDUCTIVITY CURVES FOR UNDISTURBED GREY SARNIA CLAY PERMEATED WITH LEACHATE/ETHANOL MIXTURES

This appendix presents the results of hydraulic conductivity, settlement and effluent composition for tests carried out on undisturbed samples of grey Sarnia clays permeated with leachate/ethanol mixtures at static effective stresses σ'_v = 0 kPa.

The test results are discussed in Sections 5.3.4 of this report.

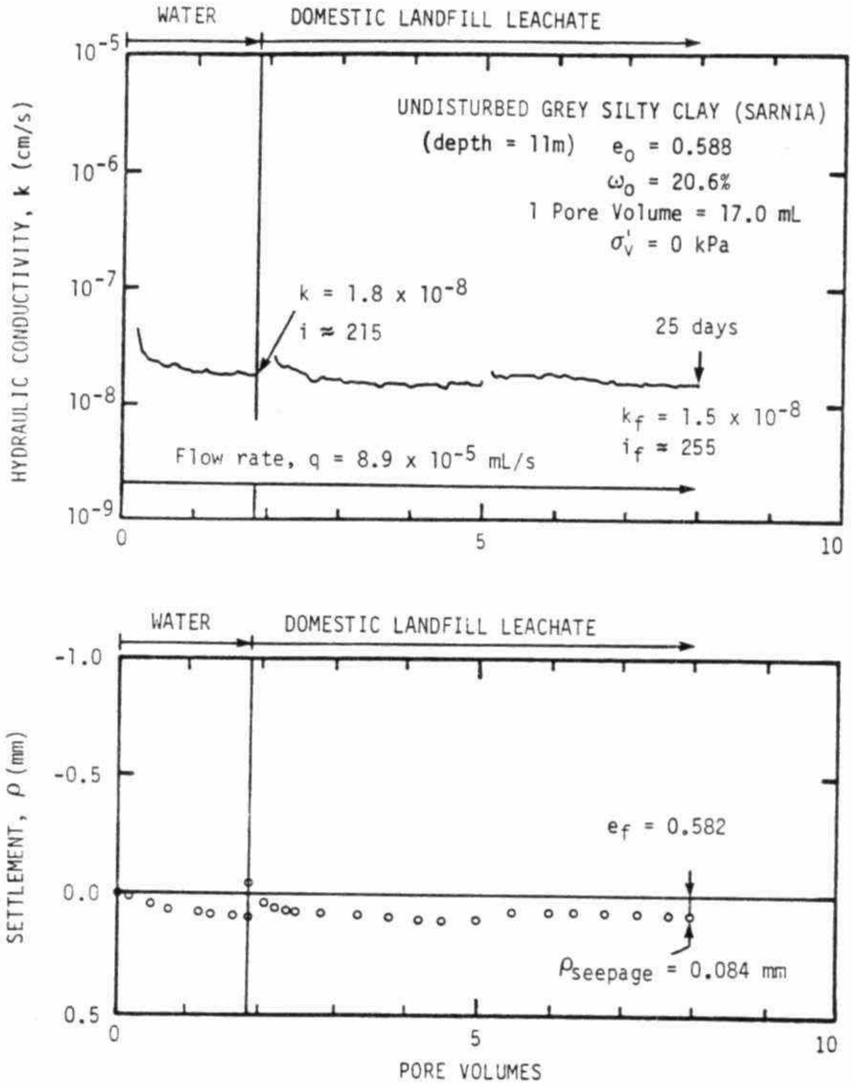

FIGURE G.1 HYDRAULIC CONDUCTIVITY, SETTLEMENT, AND EFFLUENT CHEMISTRY VS PORE VOLUMES

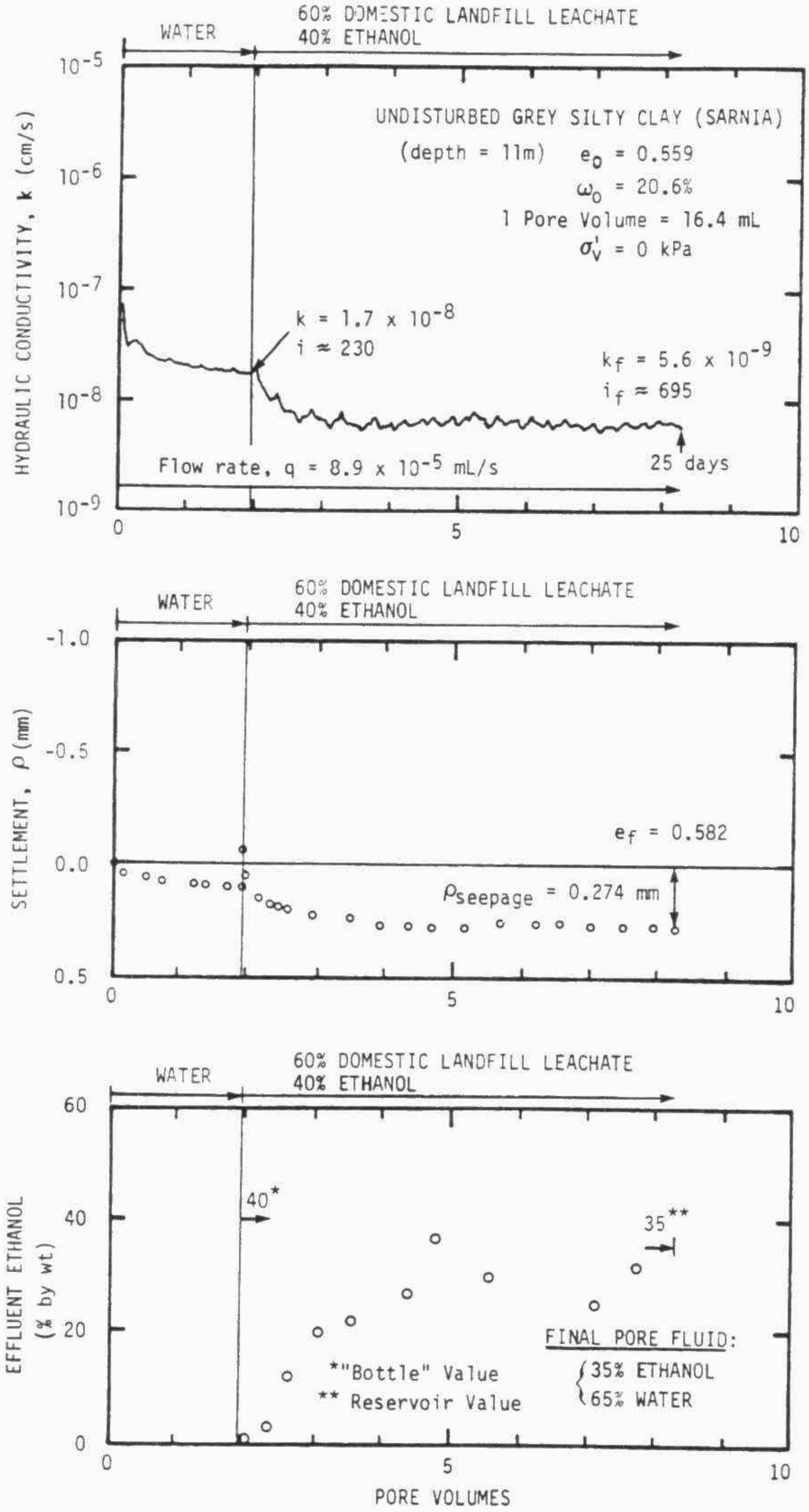

FIGURE G.2 HYDRAULIC CONDUCTIVITY, SETTLEMENT, AND EFFLUENT CHEMISTRY VS PORE VOLUMES

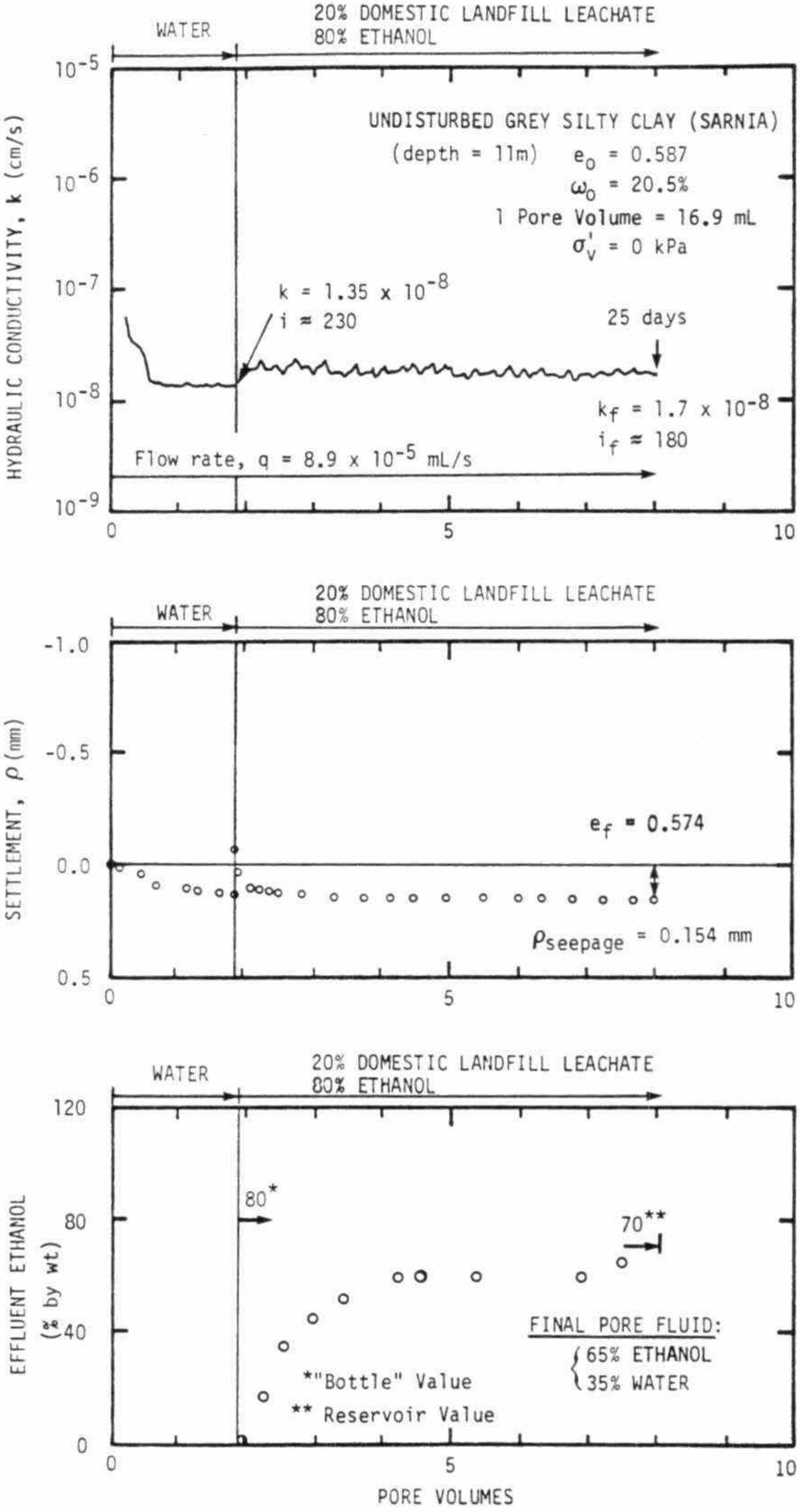

FIGURE G.3 HYDRAULIC CONDUCTIVITY, SETTLEMENT, AND EFFLUENT CHEMISTRY VS PORE VOLUMES

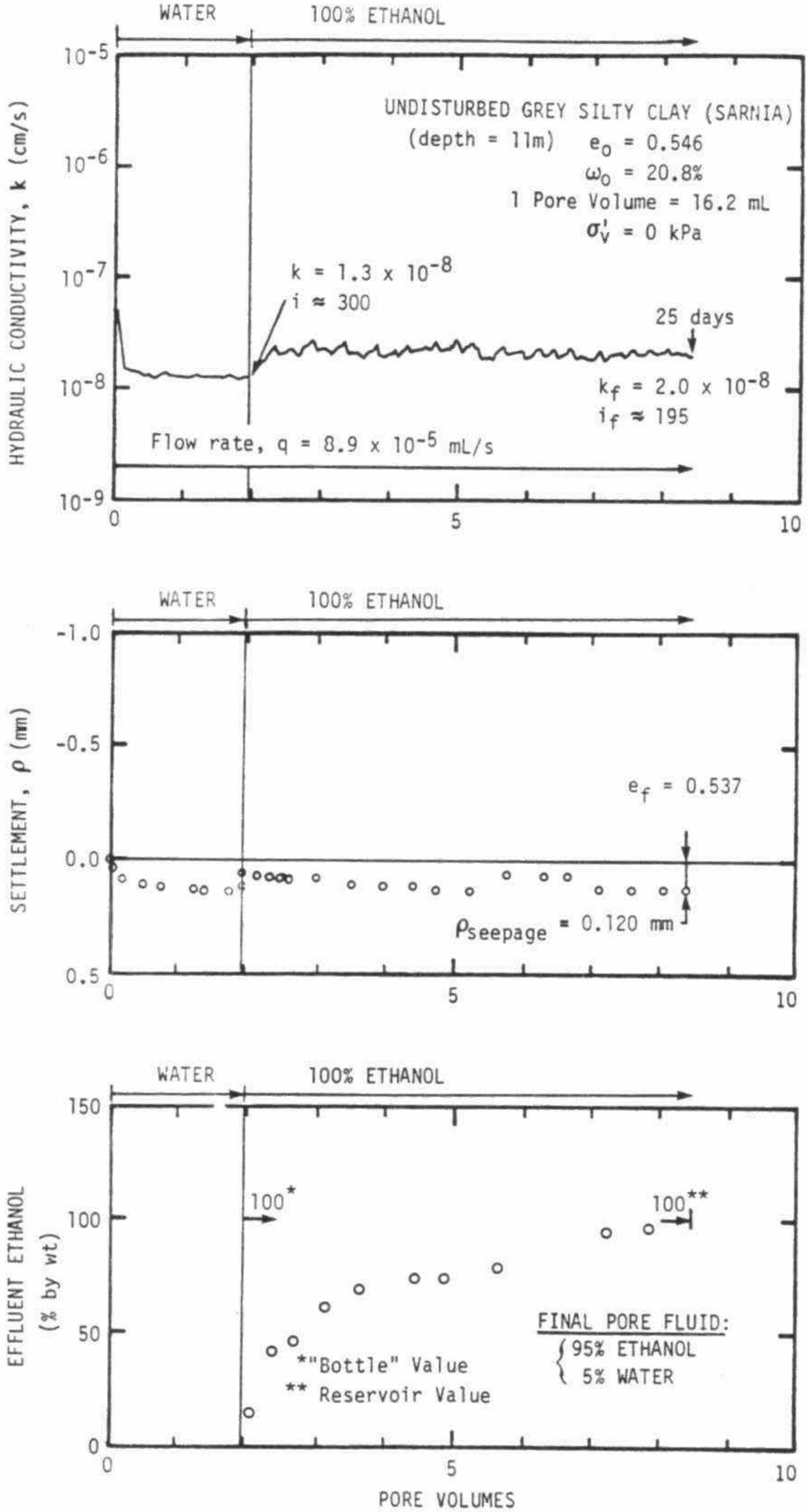

FIGURE G.4 HYDRAULIC CONDUCTIVITY, SETTLEMENT, AND EFFLUENT CHEMISTRY VS PORE VOLUMES

APPENDIX H

EFFLUENT CONCENTRATION CURVES FOR INORGANIC SPECIES WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH LEACHATE/ETHANOL MIXTURES

The figures presented in this appendix show the effluent composition versus pore volumes for water-compacted samples of brown Sarnia clays permeated 0.01 N $CaSO_4$ (water) followed by mixtures of domestic waste leachate and ethanol. These results correspond to clay/leachate compatibility shown in Figures E.3 to E.5 and discussed in Section 5.3.1 of this thesis.

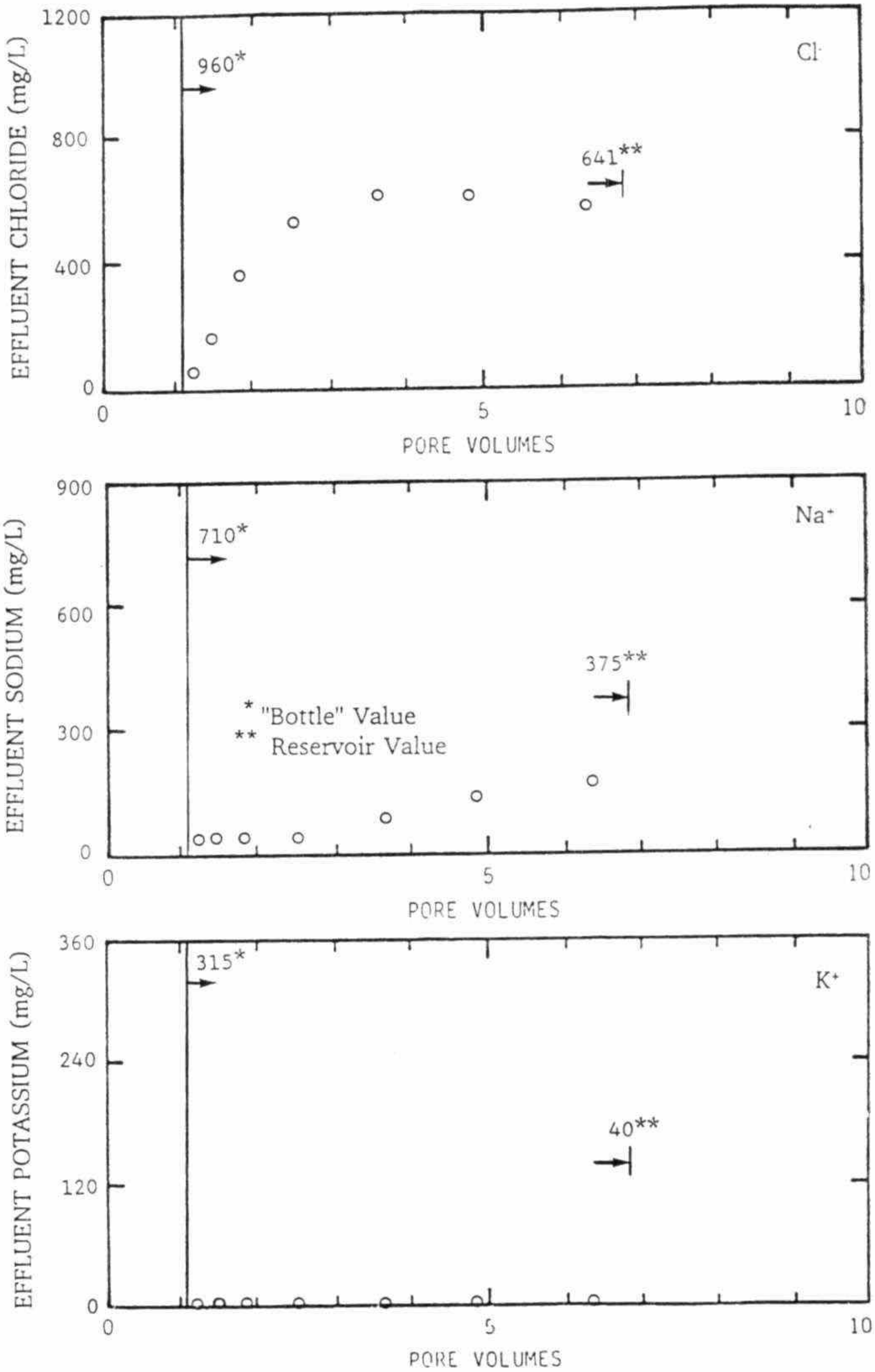

FIGURE H.1 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

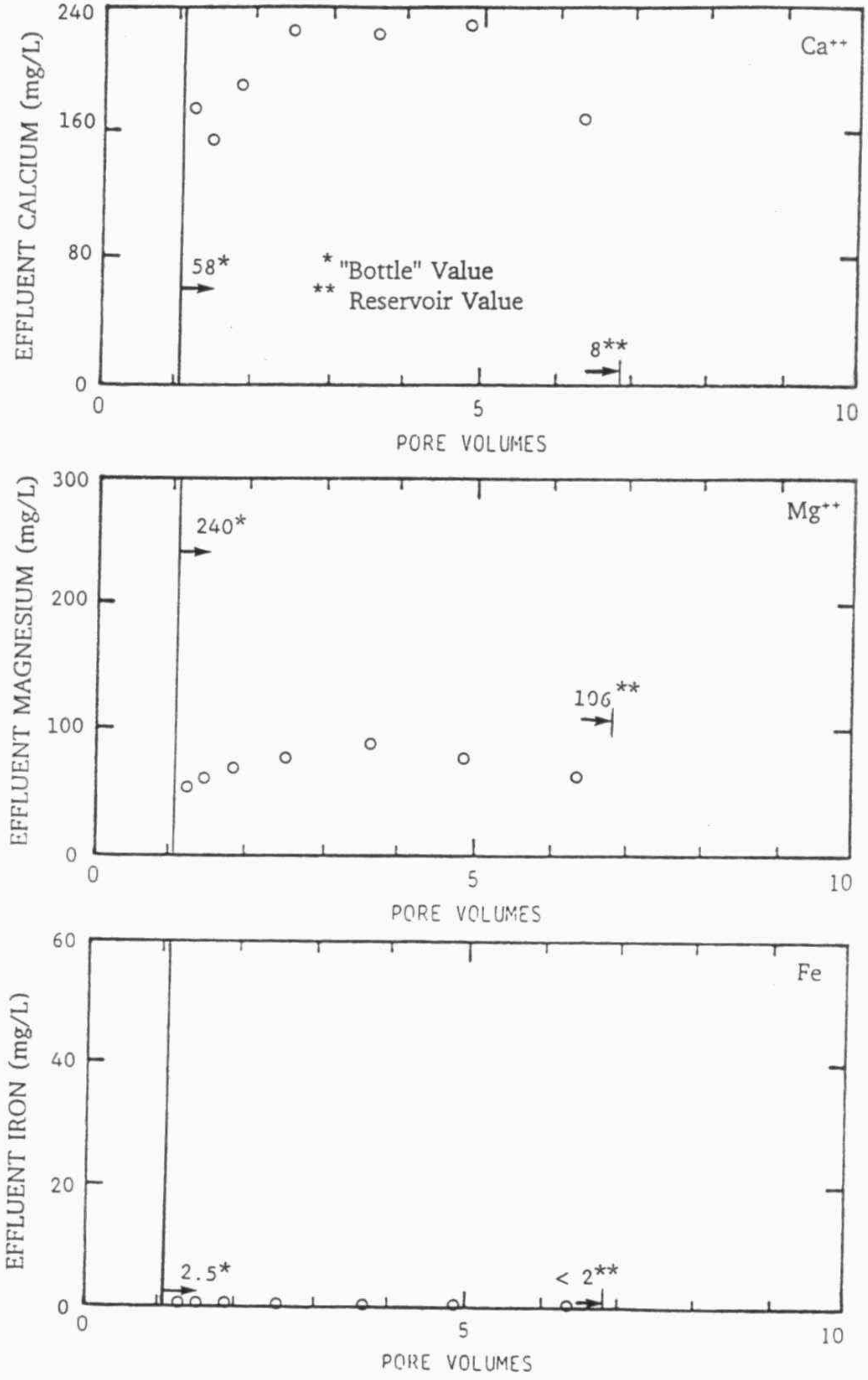

FIGURE H.2 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

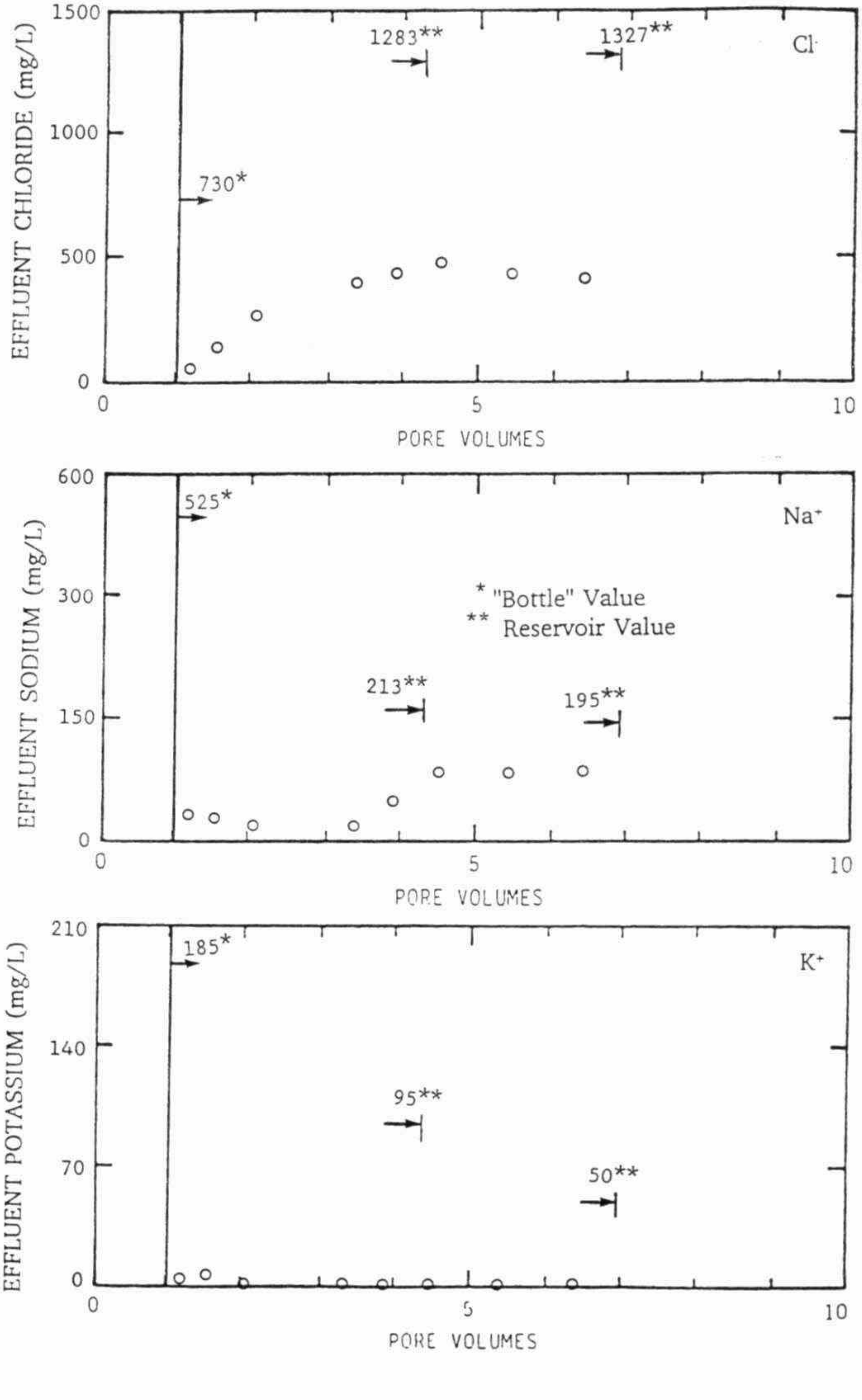

FIGURE H.3 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

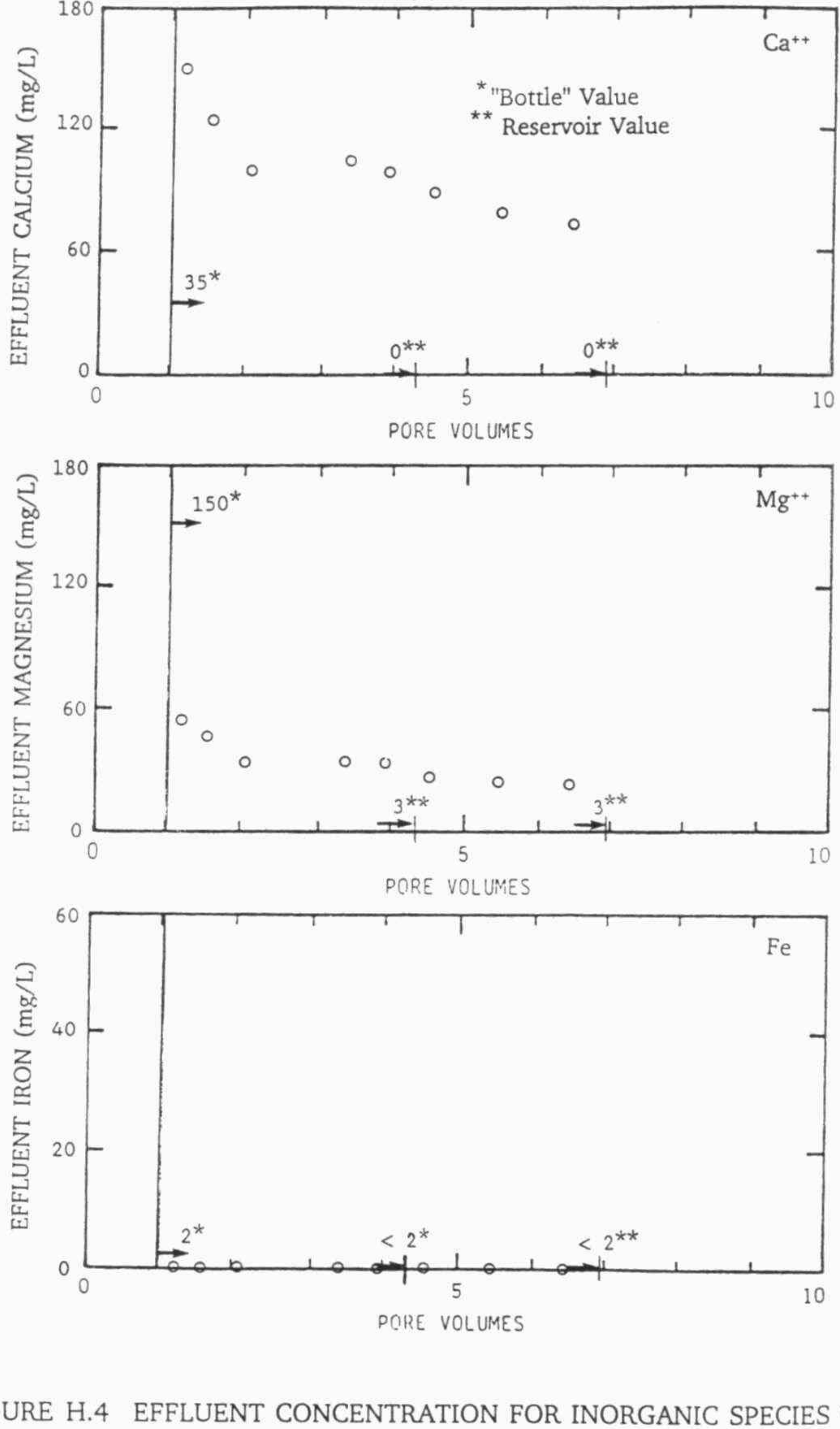

FIGURE H.4 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

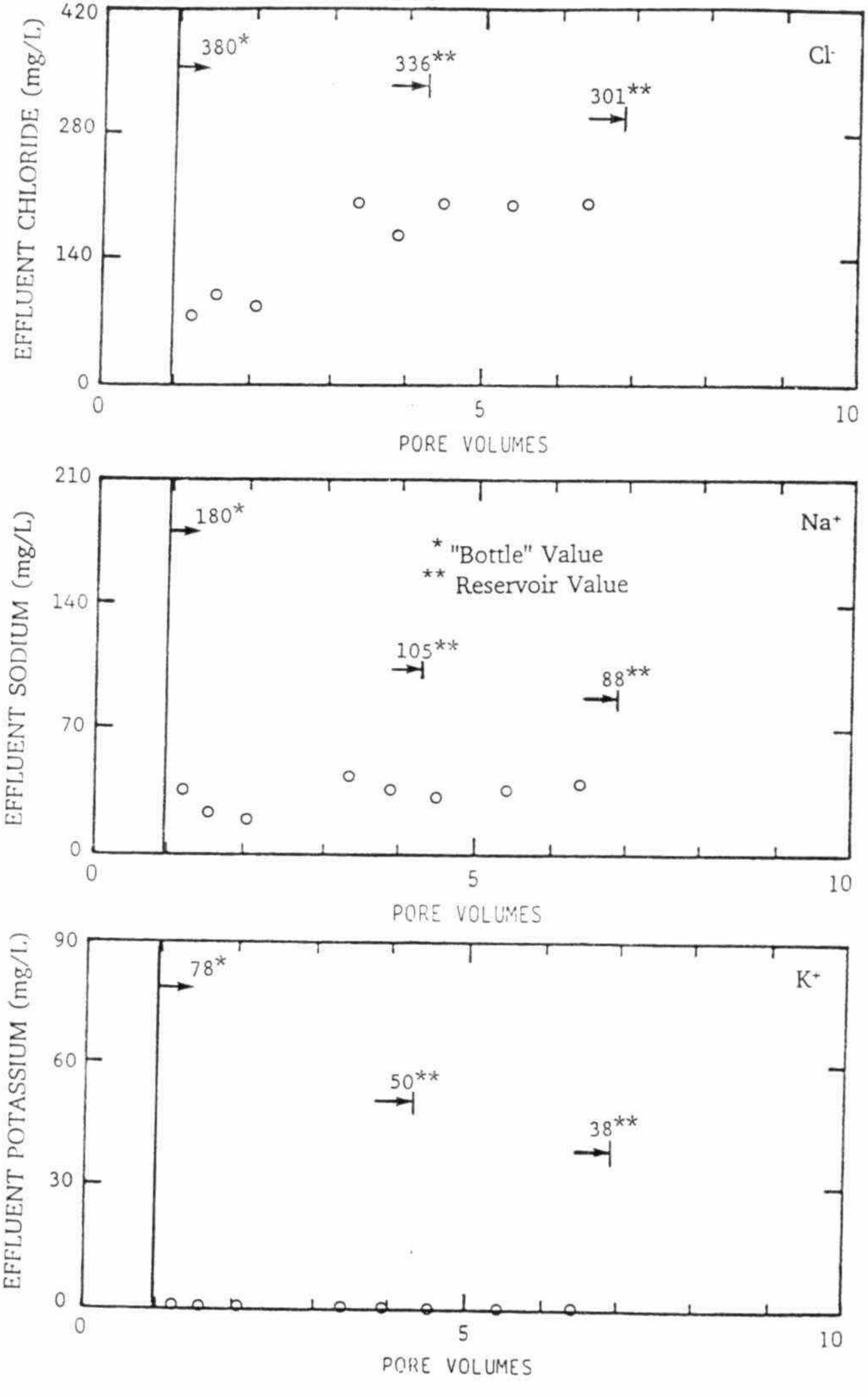

FIGURE H.5 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

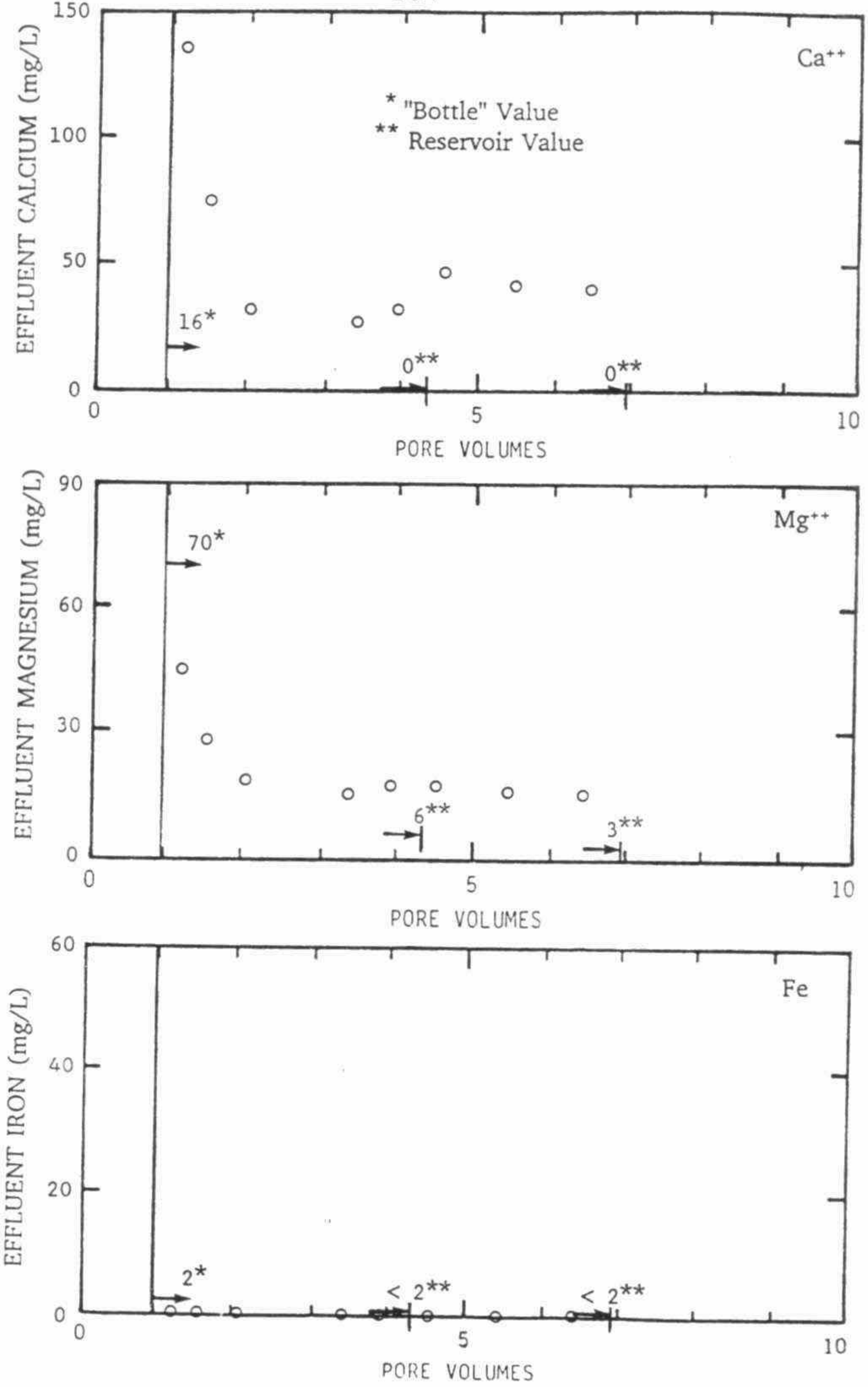

FIGURE H.6 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

APPENDIX I

EFFLUENT CONCENTRATION CURVES FOR INORGANIC SPECIES WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH LEACHATE/DIOXANE MIXTURES

The figures presented in this appendix show the effluent composition versus pore volumes for water-compacted samples of brown Sarnia clay permeated 0.01 N $CaSO_4$ (water) followed by mixtures of domestic waste leachate and dioxane. These results correspond to clay/leachate compatibility shown in Figures F.1 to F.5 and discussed in Section 5.3.2 of this thesis.

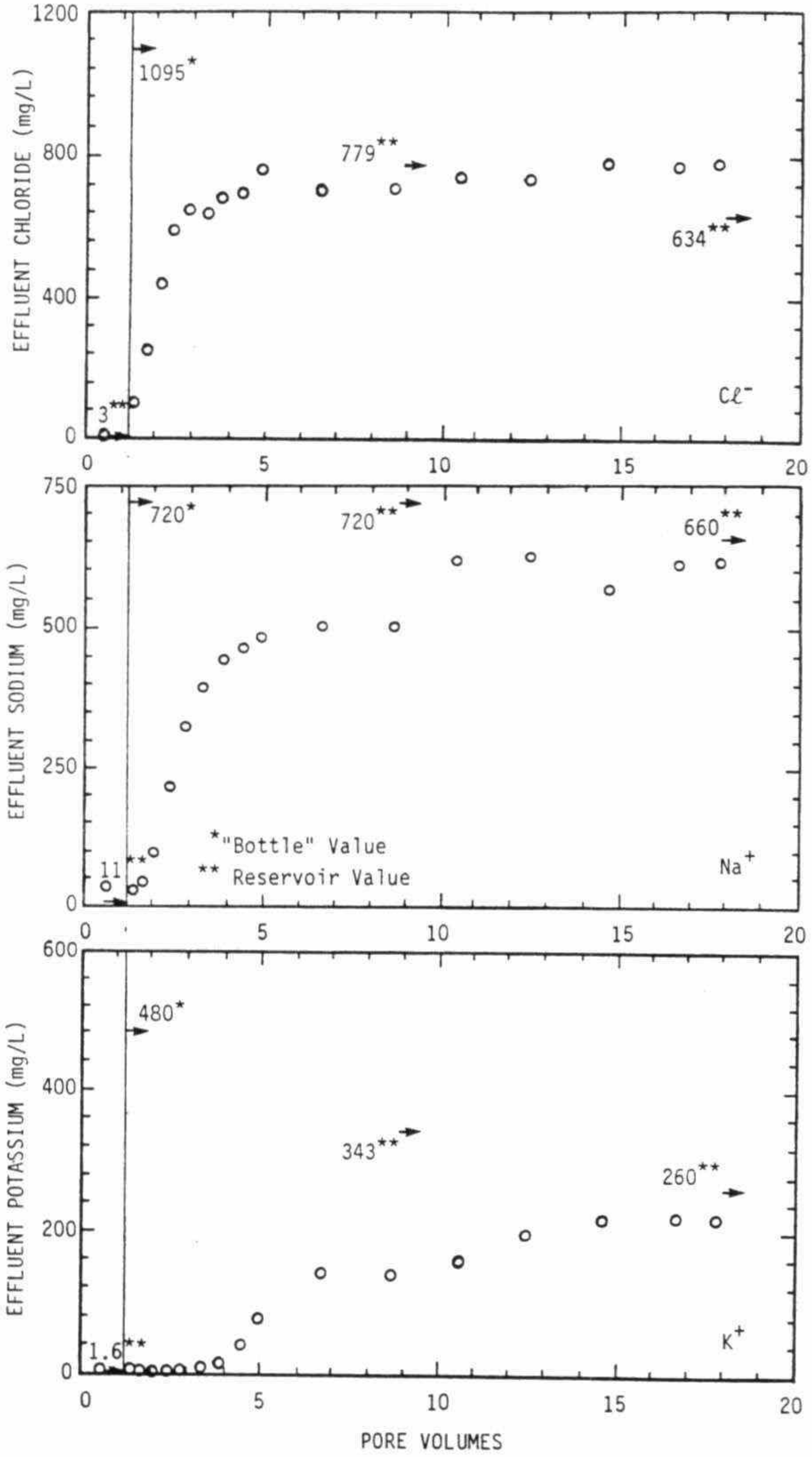

FIGURE I.1 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

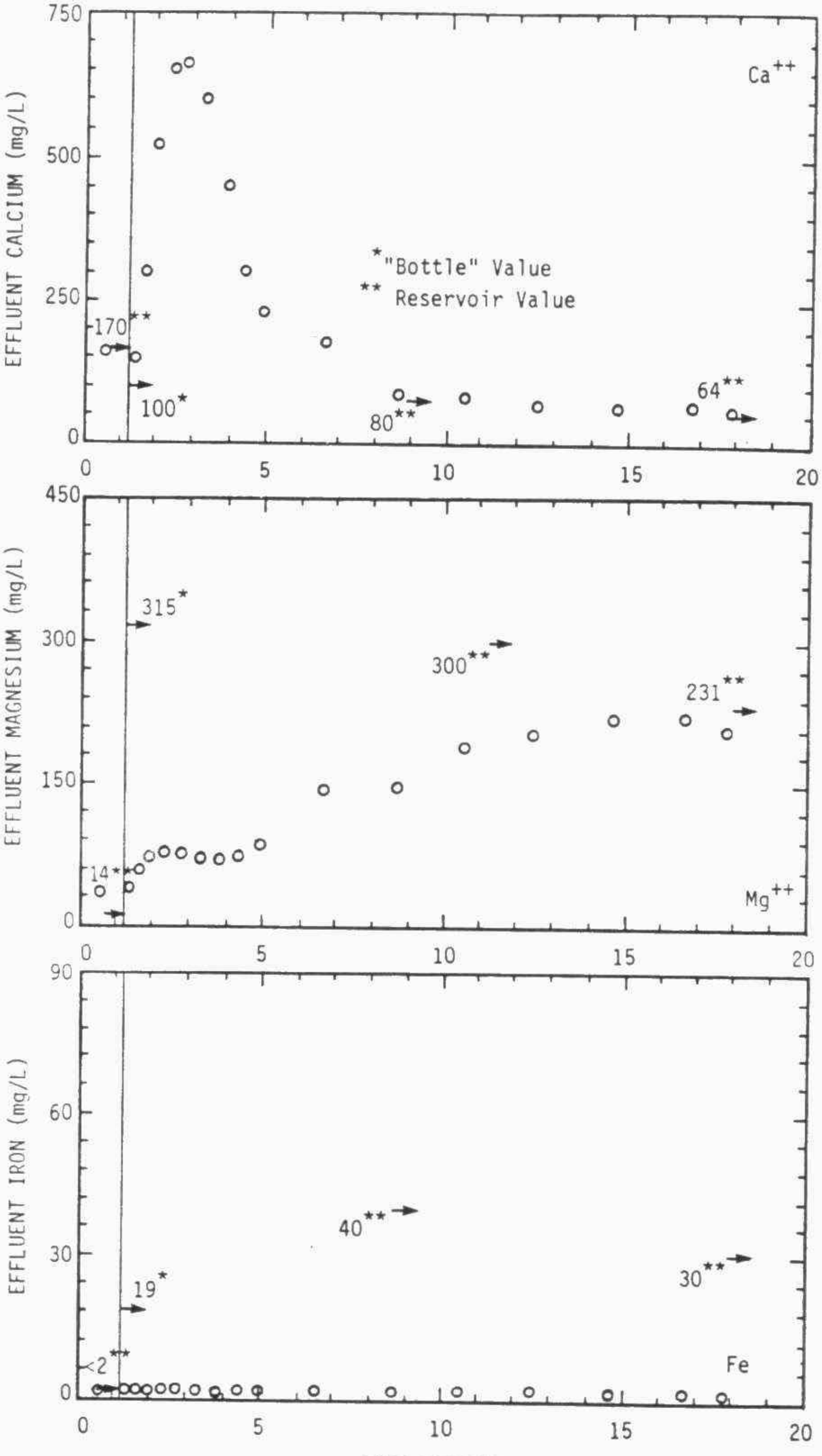

FIGURE I.2 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

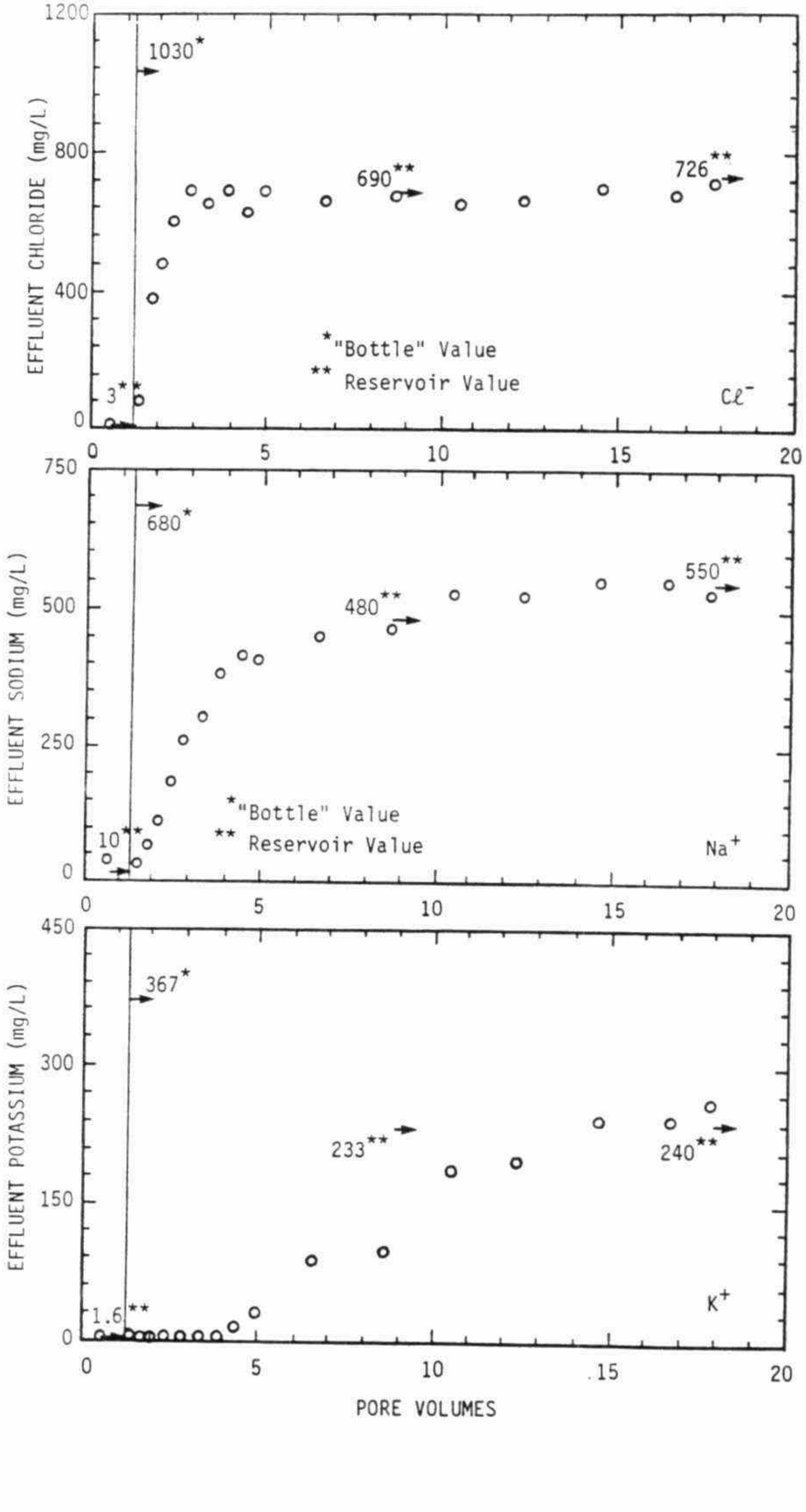

FIGURE I.3 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

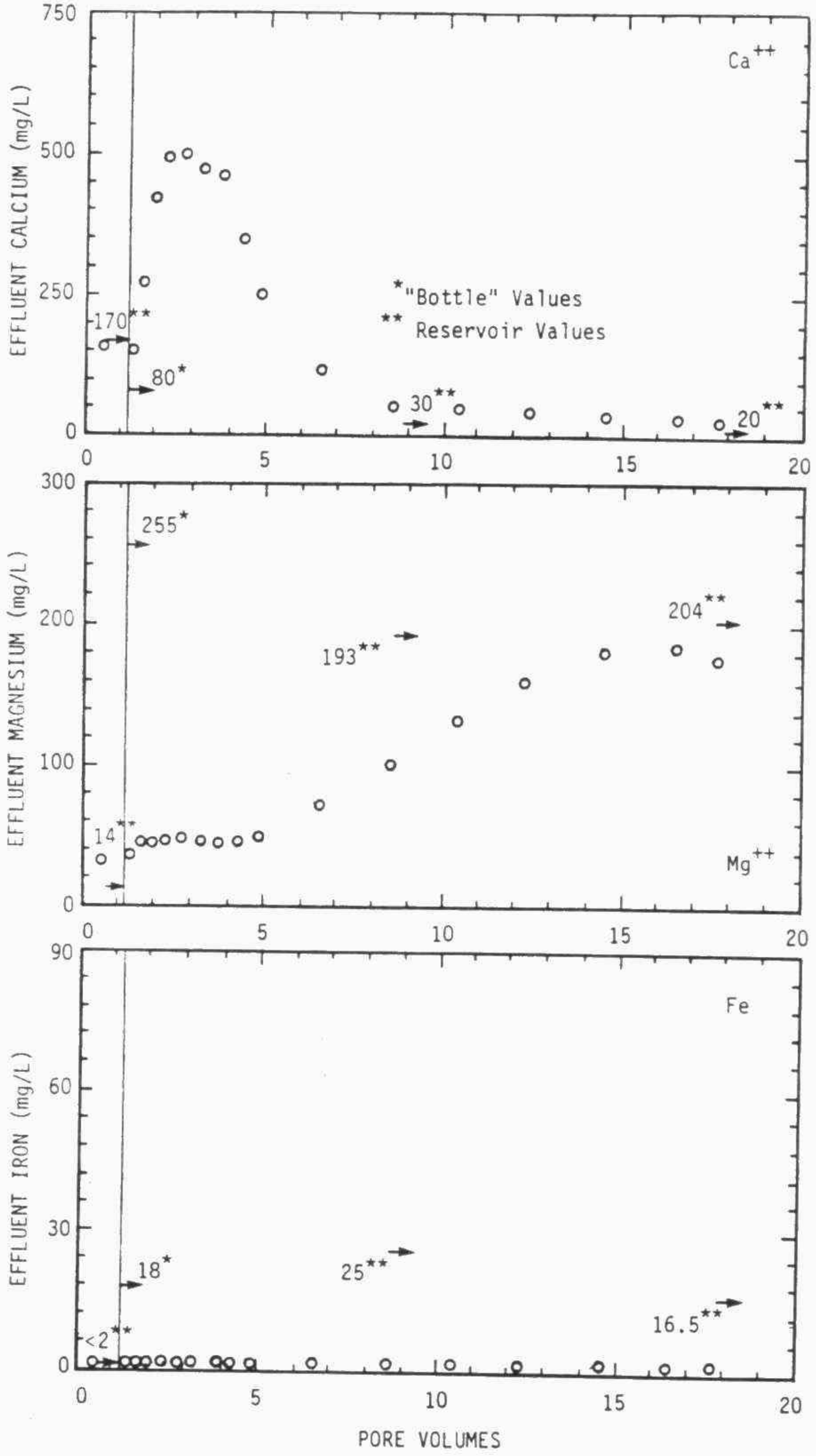

FIGURE I.4 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

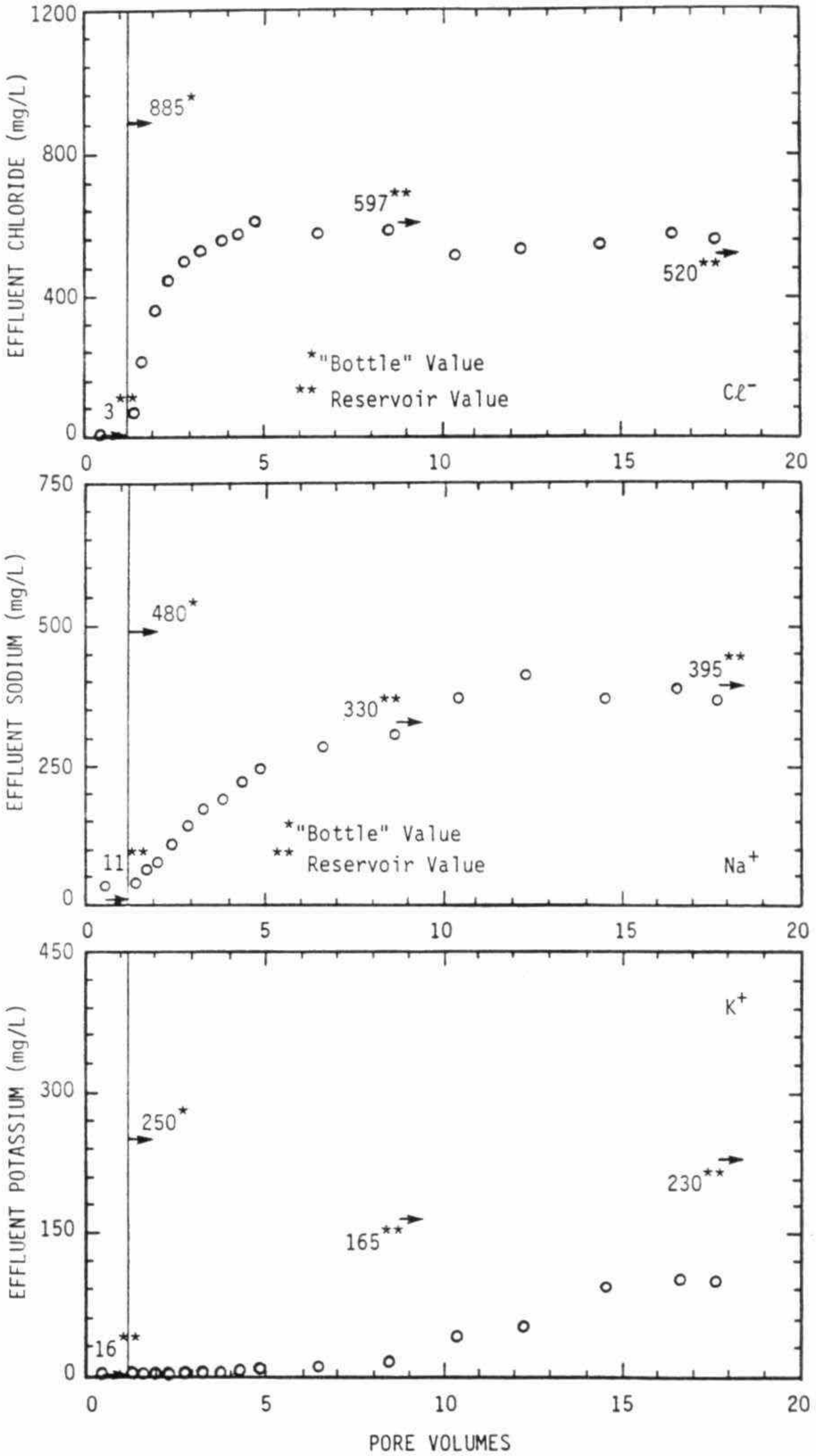

FIGURE I.5 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

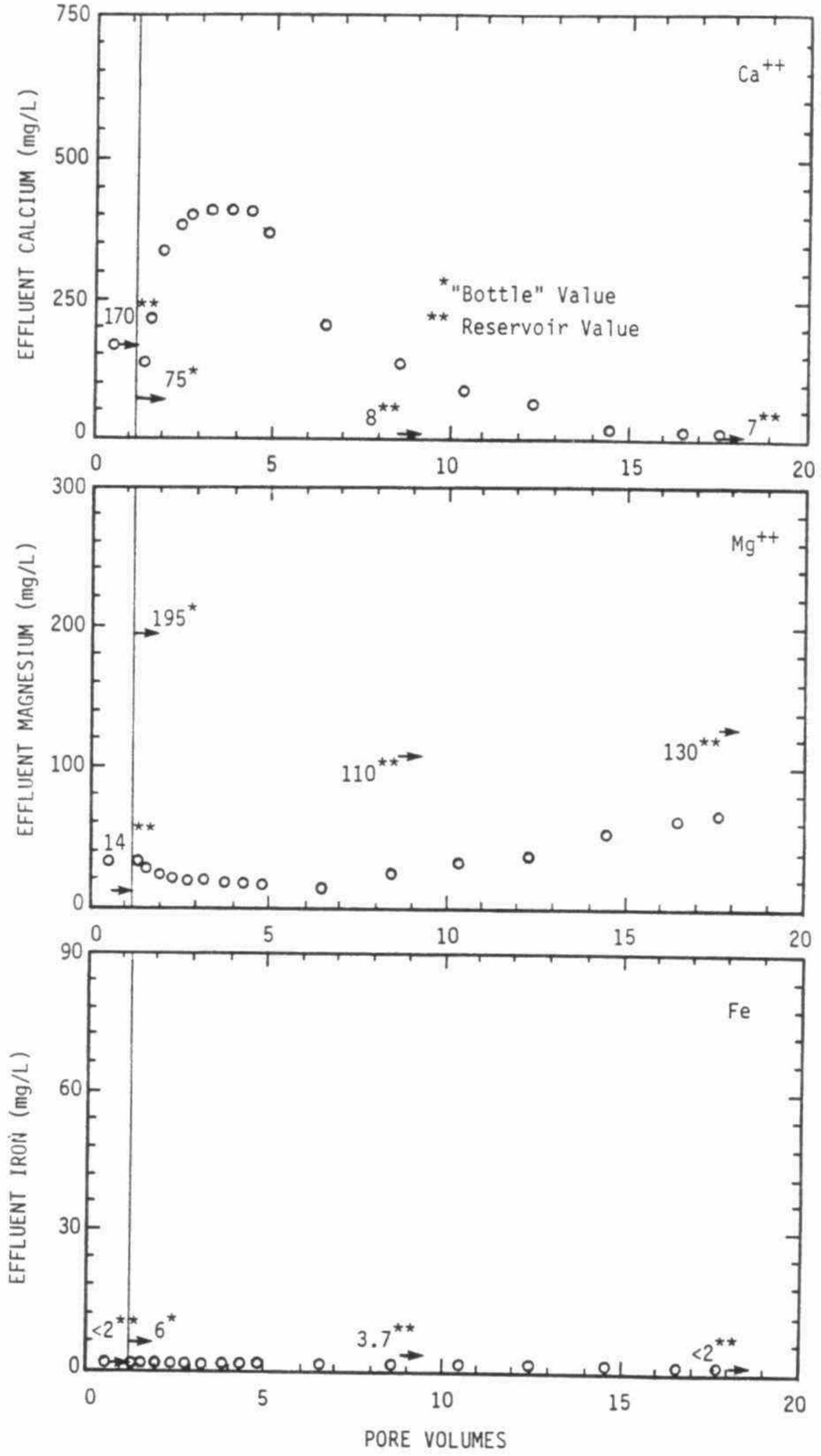

FIGURE I.6 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

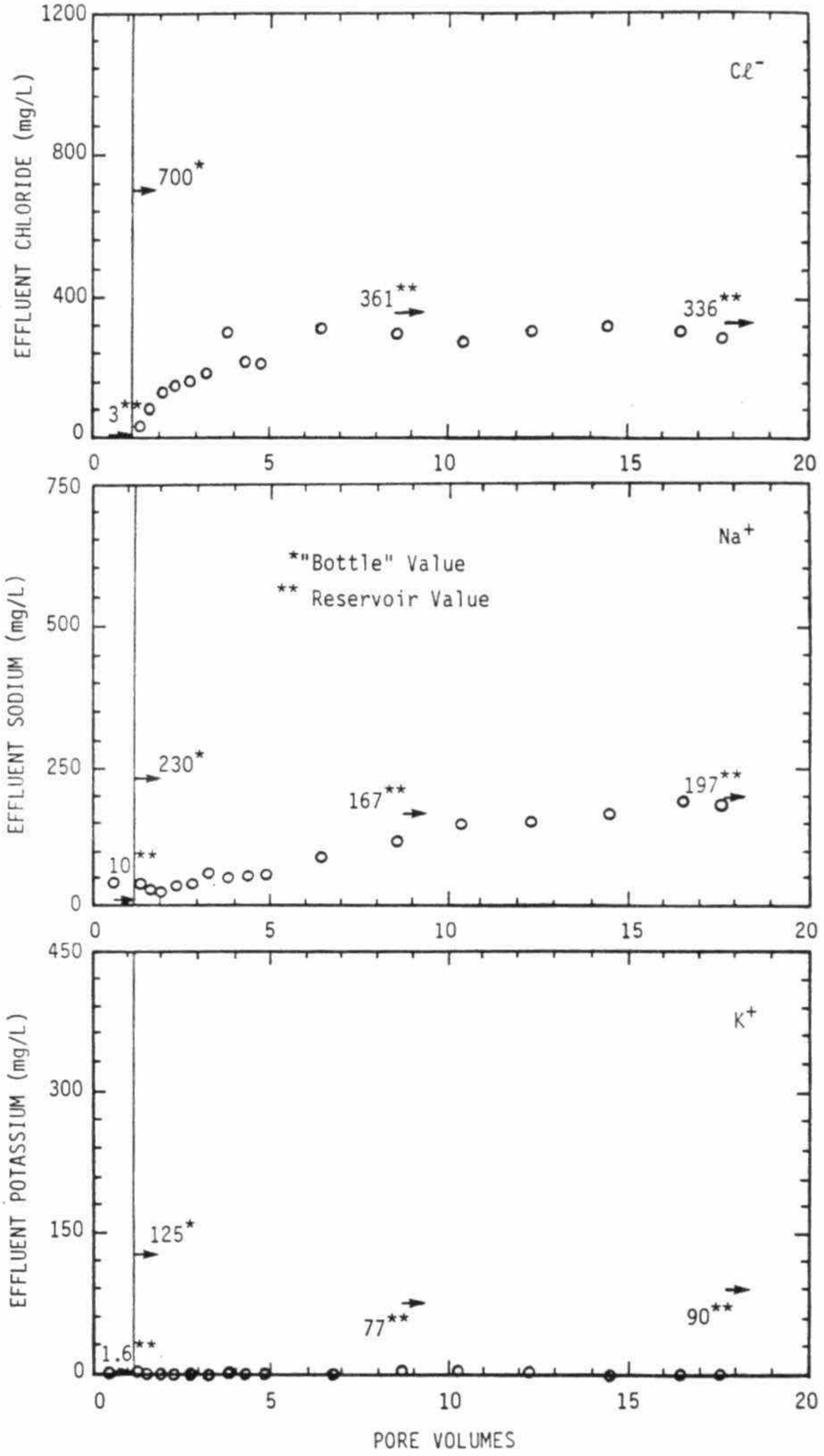

FIGURE I.7 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

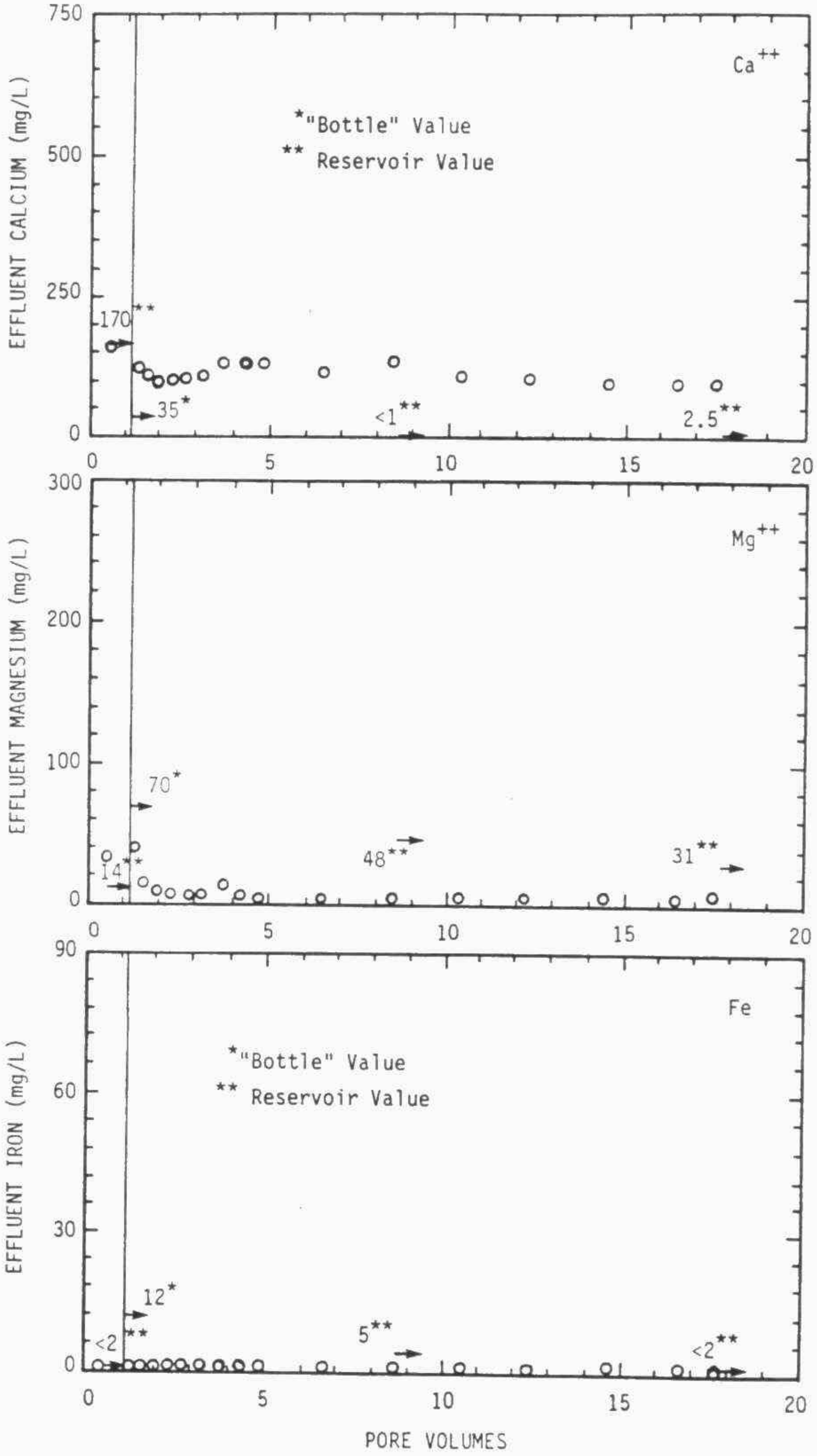

FIGURE I.8 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

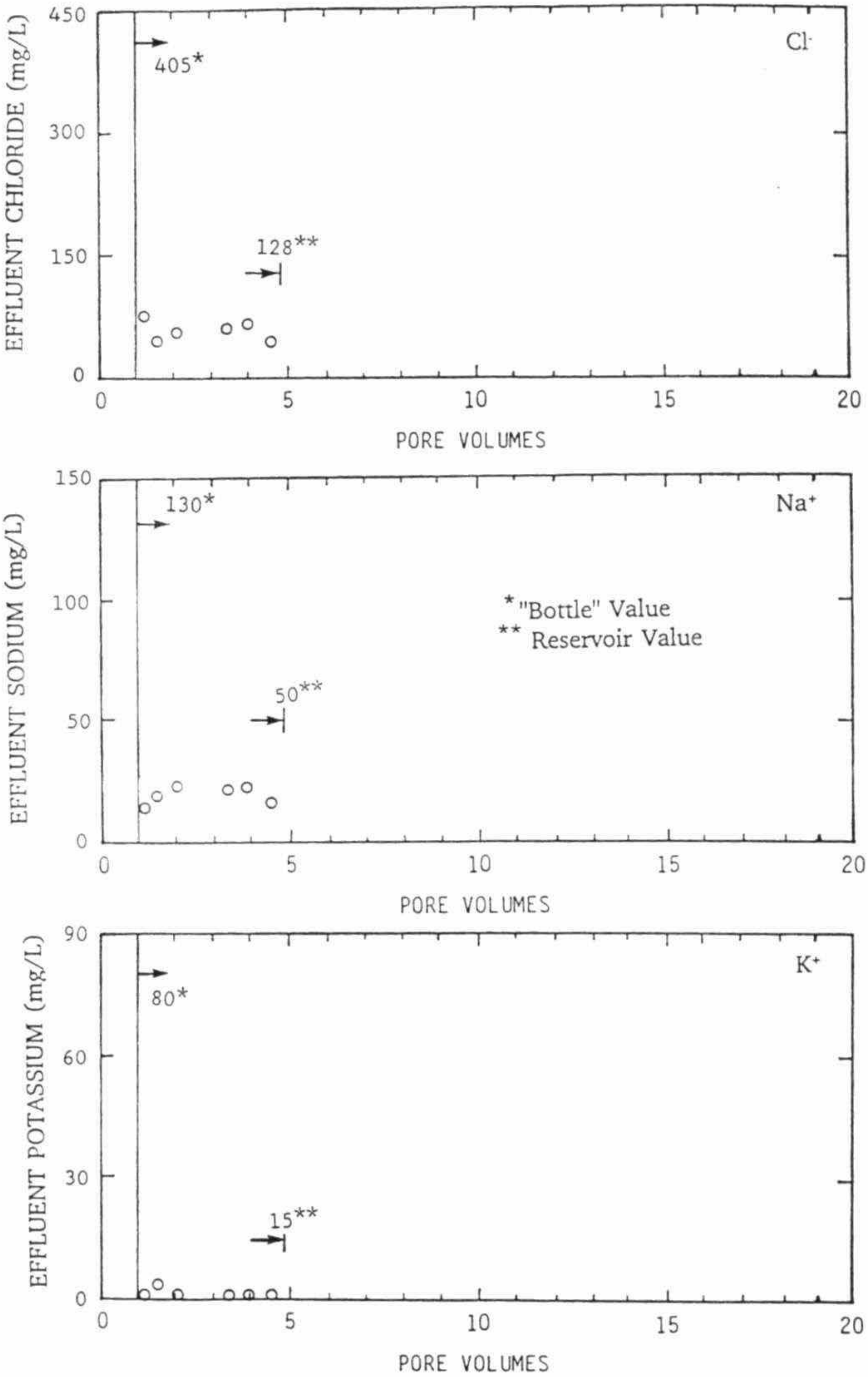

FIGURE I.9 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

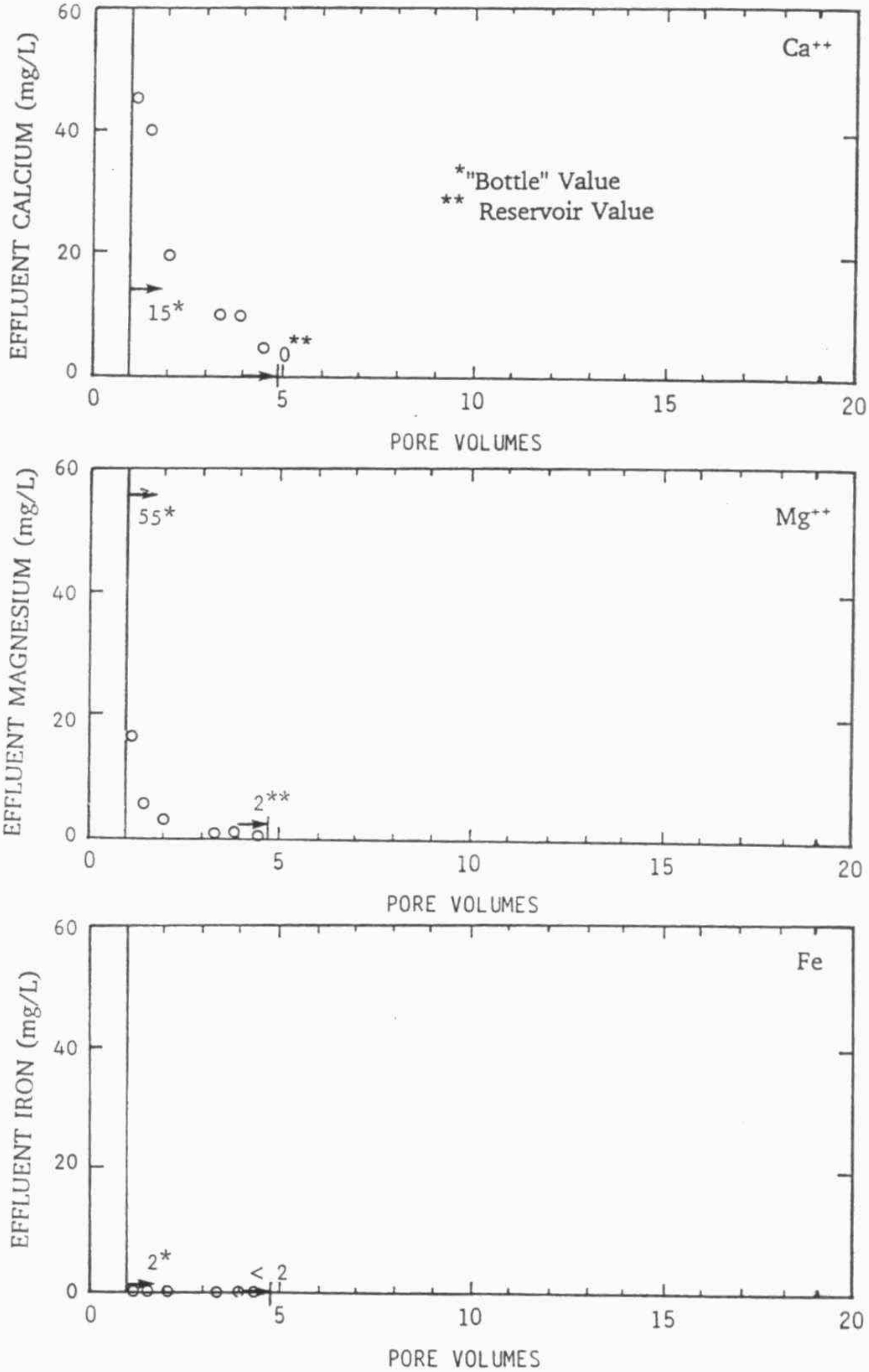

FIGURE I.10 EFFLUENT CONCENTRATION FOR INORGANIC SPECIES VS PORE VOLUMES

APPENDIX J

PORE SIZE DISTRIBUTION CURVES OBTAINED BY MERCURY INTRUSION POROSIMETRY

The results of pore size analyses by mercury intrusion porosimetry are presented in this chapter. Each figure includes an lower graph for the cumulative intruded pore volume (cubic centimetres per gram of dry soil), and an upper graph for the incremental intruded pore volume (also expressed in cm^3/g). The data in the upper graph are calculated from the measured values of pore intrusion (lower graph), and provides a clear picture of the distribution of pores in the tested specimen.

The samples were analyzed as part of the post-testing assessment of the hydraulic conductivity studies. These studies include:

Ethanol/water/brown Sarnia clay mixtures (Figures J.1 to J.9)

Ethanol/leachate/brown Sarnia clay mixtures (Figures J.10 to J.17)

Ethanol/water/kaolinite mixtures (Figures J.18 to J.22)

Dioxane/water/brown Sarnia clay mixtures (Figures J.23 to J.26)

Dioxane/leachate/brown Sarnia clay mixtures (Figures J.27 to J.29)

Water-compacted brown Sarnia clay permeated with water, σ'_v = 0 kPa (Figure J.30)

Water-compacted brown Sarnia clay permeated with water and then by leachate/ethanol mixtures, σ'_v = 0 kPa (Figures J.31 to J.34)

Water-compacted brown Sarnia clay permeated with water and then by leachate/dioxane mixtures, σ'_v = 0 kPa (Figures J.35 to J.39)

Water-compacted brown Sarnia clay permeated with water and then by leachate/dioxane mixtures, σ'_v = 40 to 160 kPa (Figures J.40 to J.47)

Undisturbed samples of grey Sarnia clay permeated with water and then by leachate/ethanol mixtures, σ'_v = 0 kPa (Figures J.48 to J.52)

The soil specimens are trimmed by a razor blade down to a 10 mm cube and the pore fluids are removed by freeze-drying. This is done by dipping the specimens in a pentane bath for approximately one minute. The pentane bath is kept at a temperature of about -130 °C using liquid nitrogen as the cooling source. The soil specimens are subsequently placed under vacuum (< 0.07 mm Hg) and kept overnight. During this period the frozen pore fluid is removed from the soil by sublimation. The freeze-drying technique employed was found to successfully prevent volume changes for of water saturated soil samples.

The analyses were performed using a Micromeritics Poresizer 9310, which generates hydraulic pressures in excess of 30,000 psi (207 MPa). At this pressure level, mercury intrusion can reach pores of ~ 6 nm.

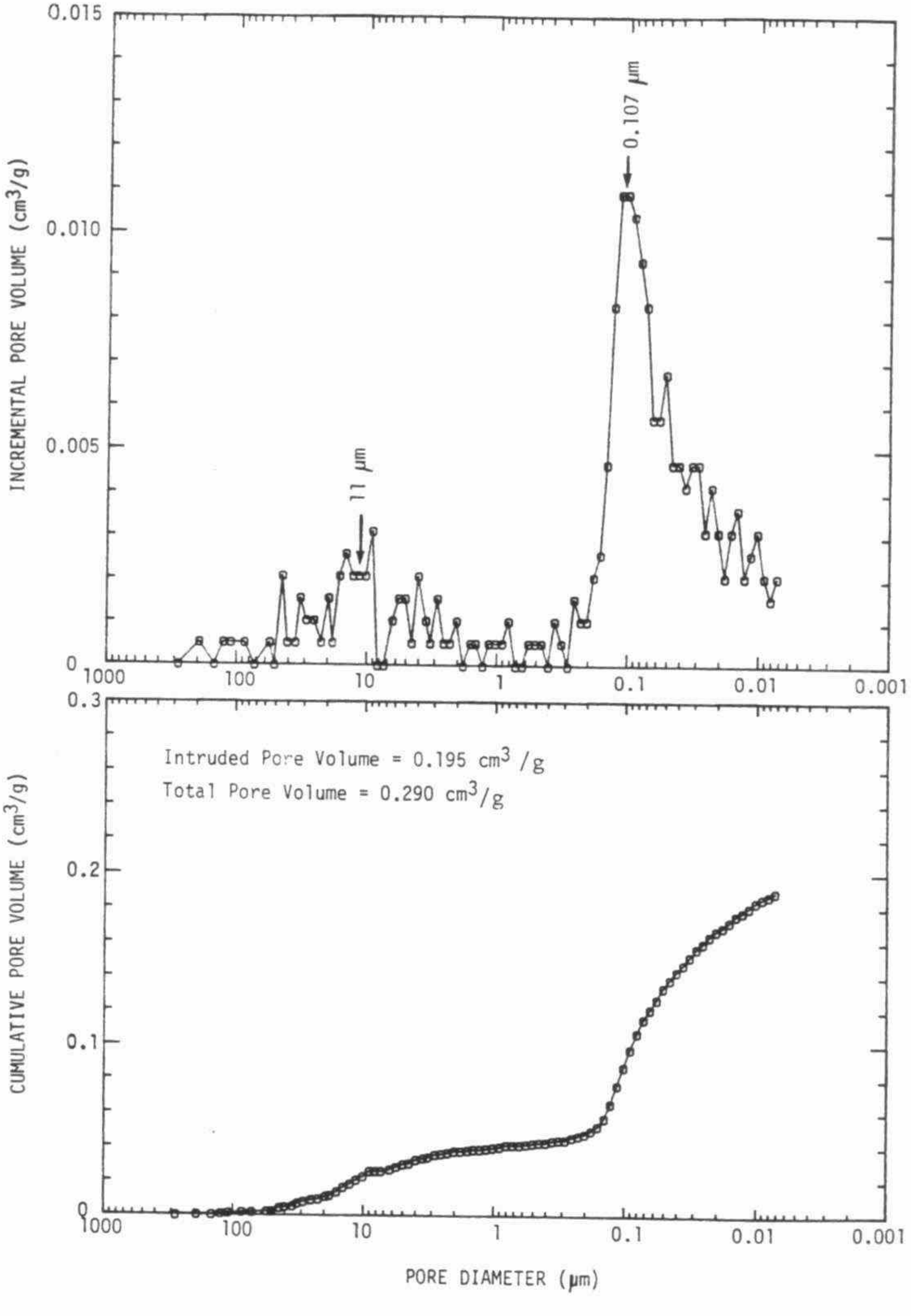

FIGURE J.1 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 100% WATER

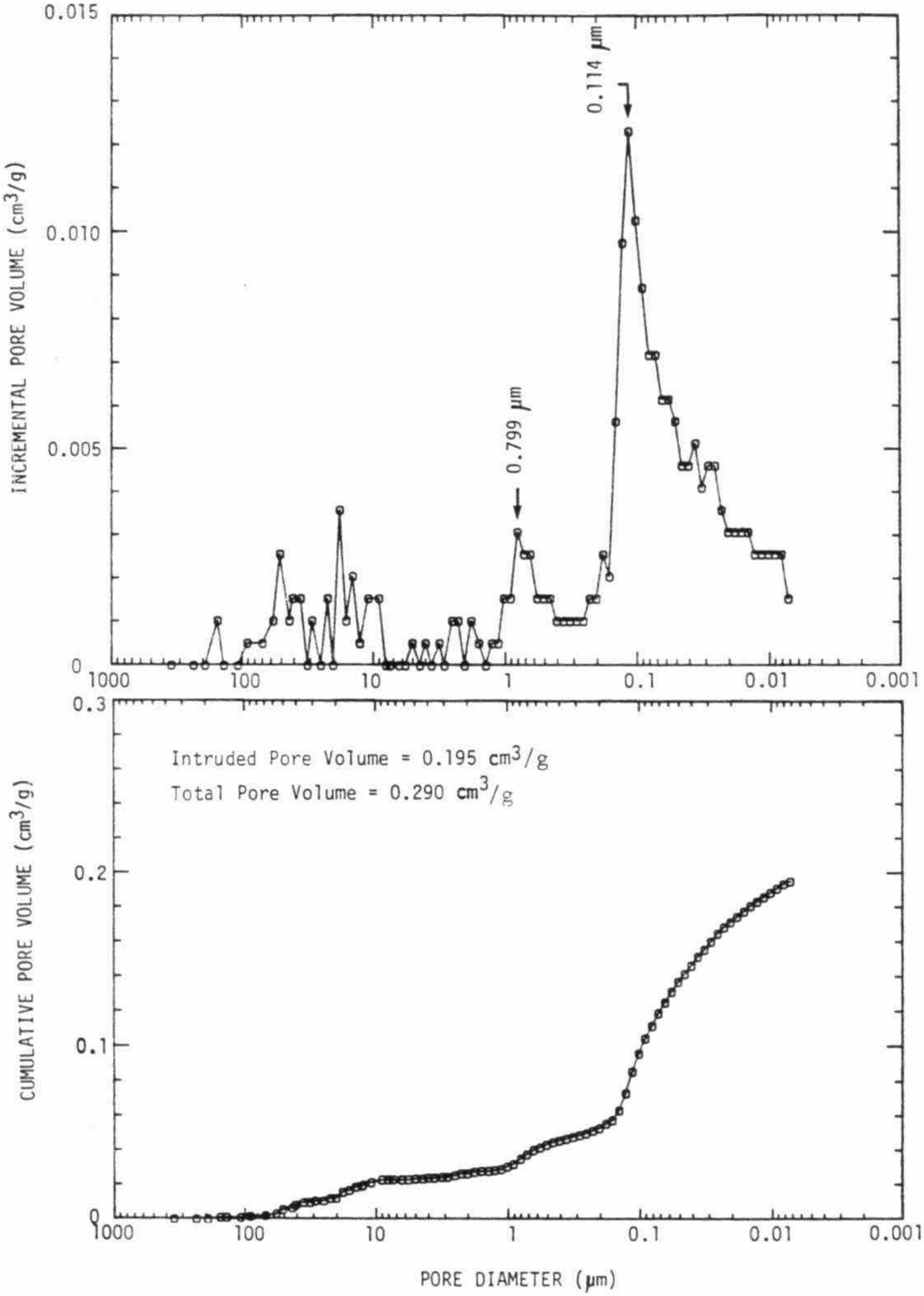

FIGURE J.2 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 10% ETHANOL - 90% WATER

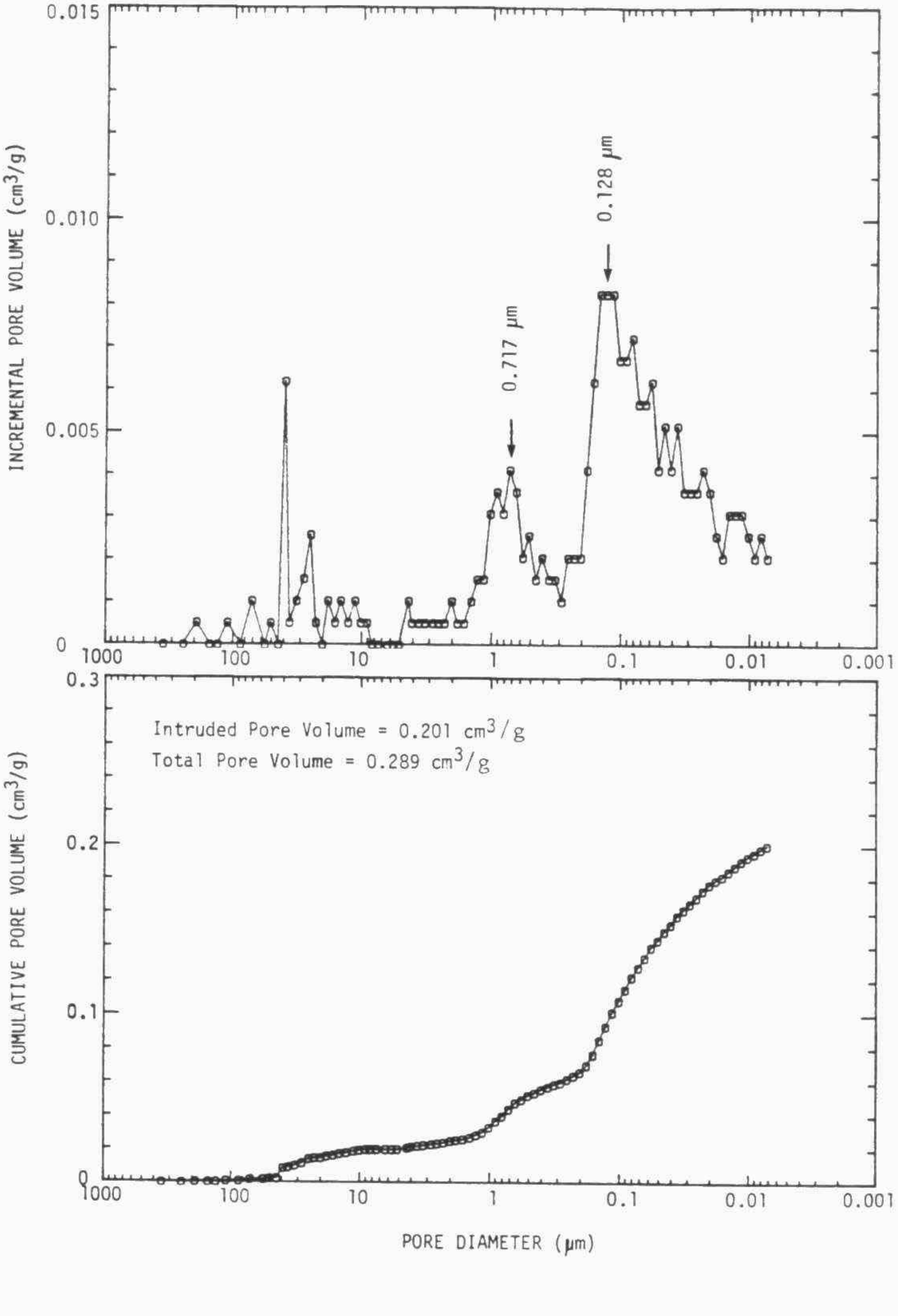

FIGURE J.3 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 20% ETHANOL - 80% WATER

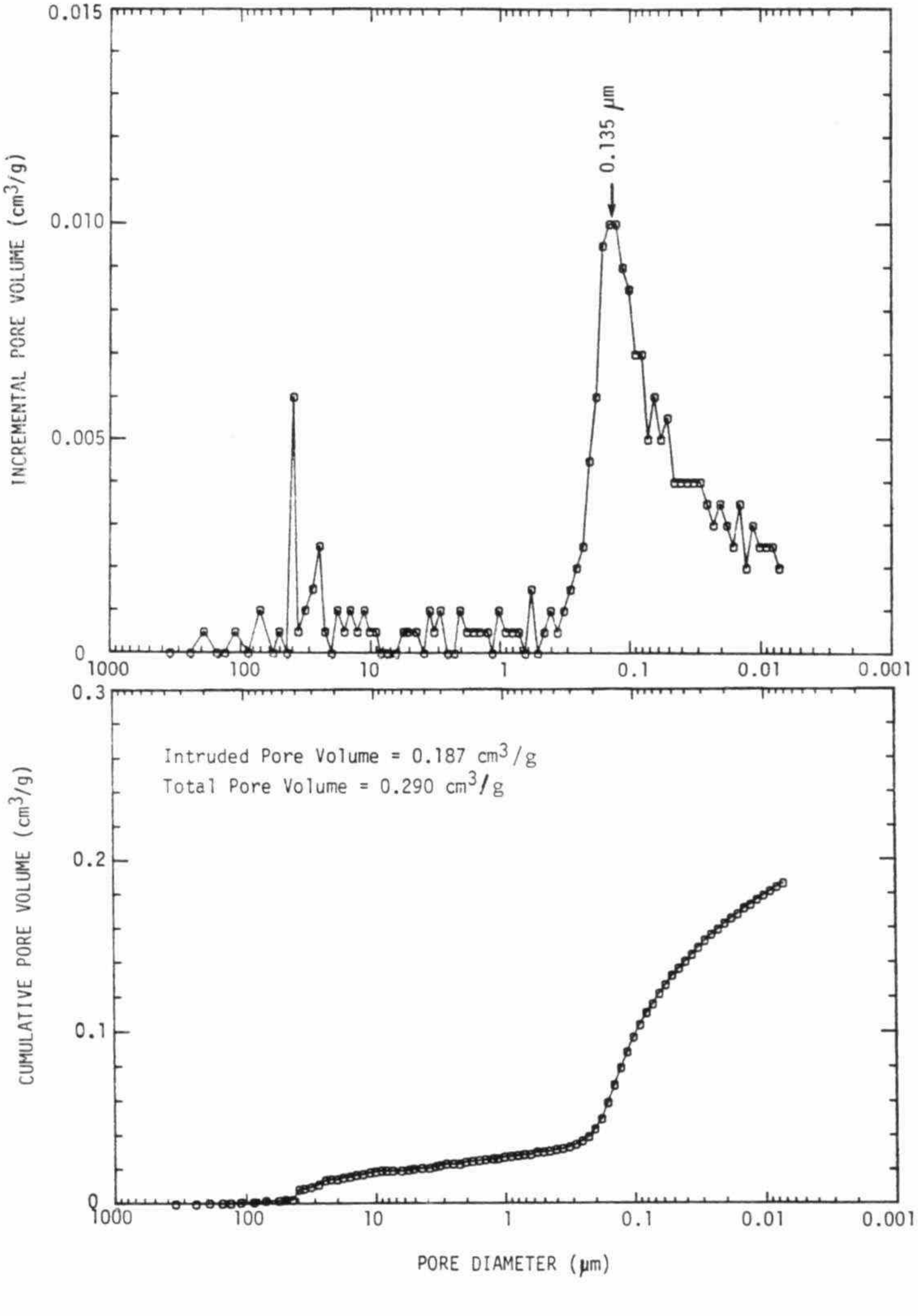

FIGURE J.4 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 35% ETHANOL - 65% WATER

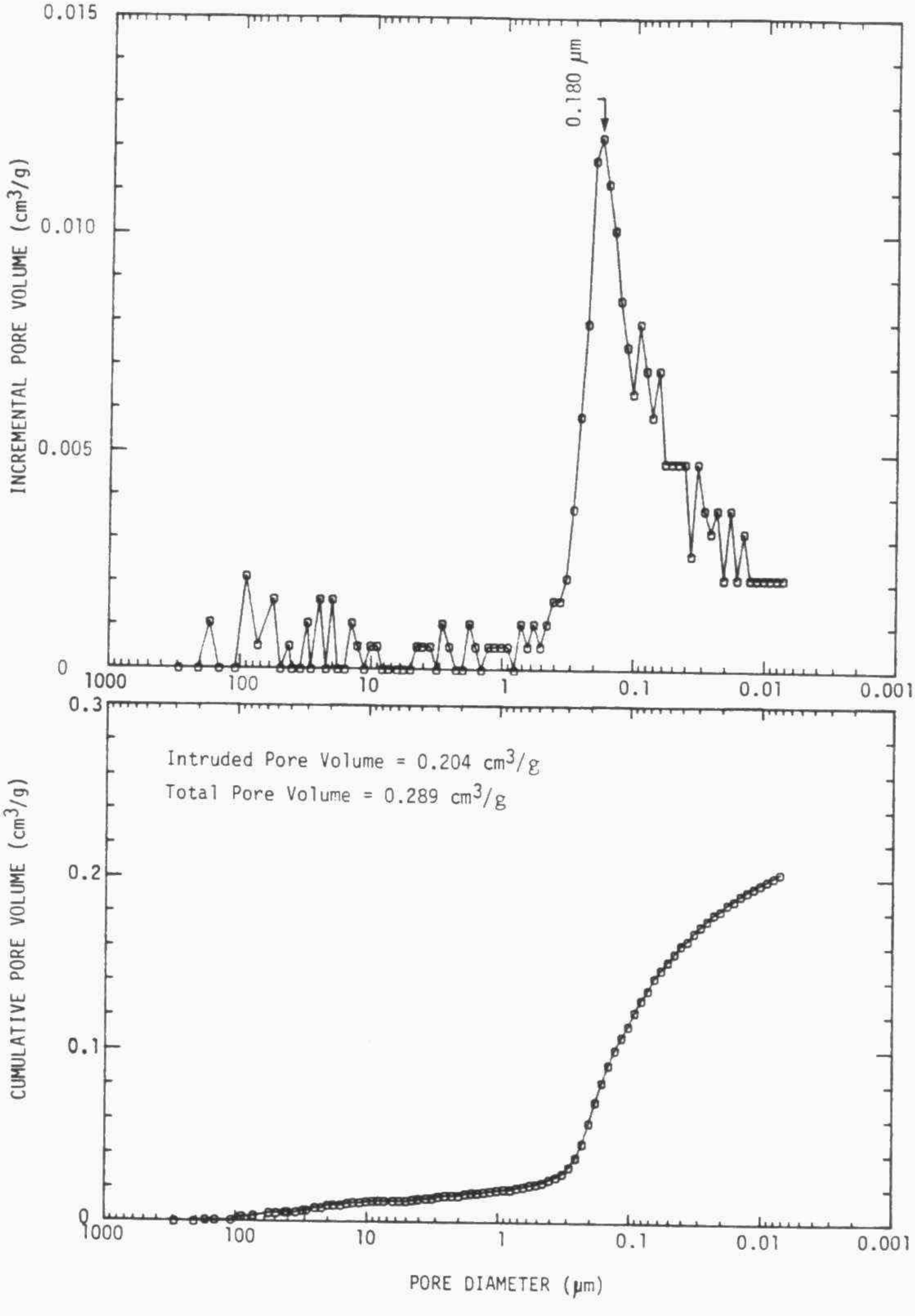

FIGURE J.5 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 50% ETHANOL - 50% WATER

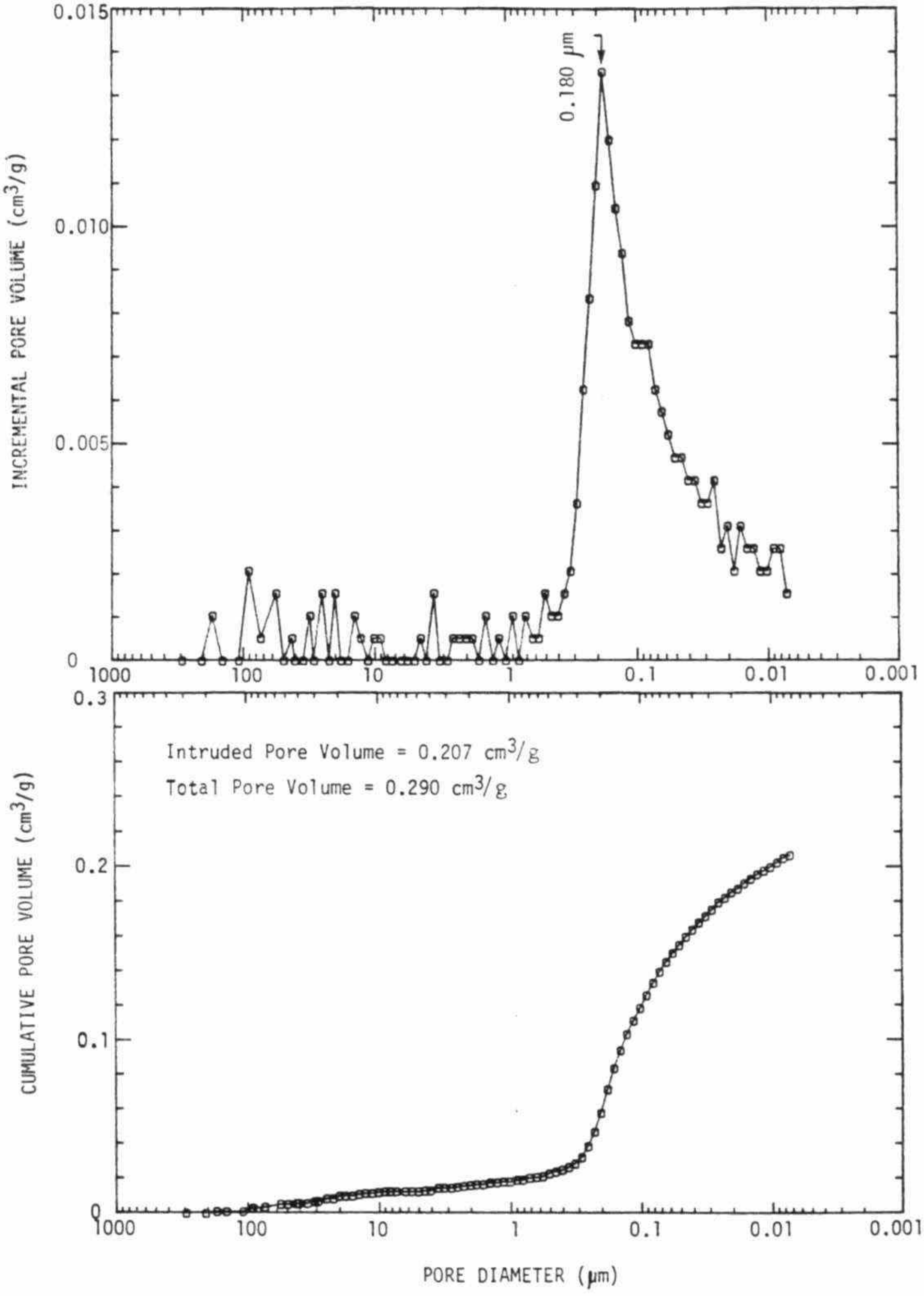

FIGURE J.6 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 65% ETHANOL - 35% WATER

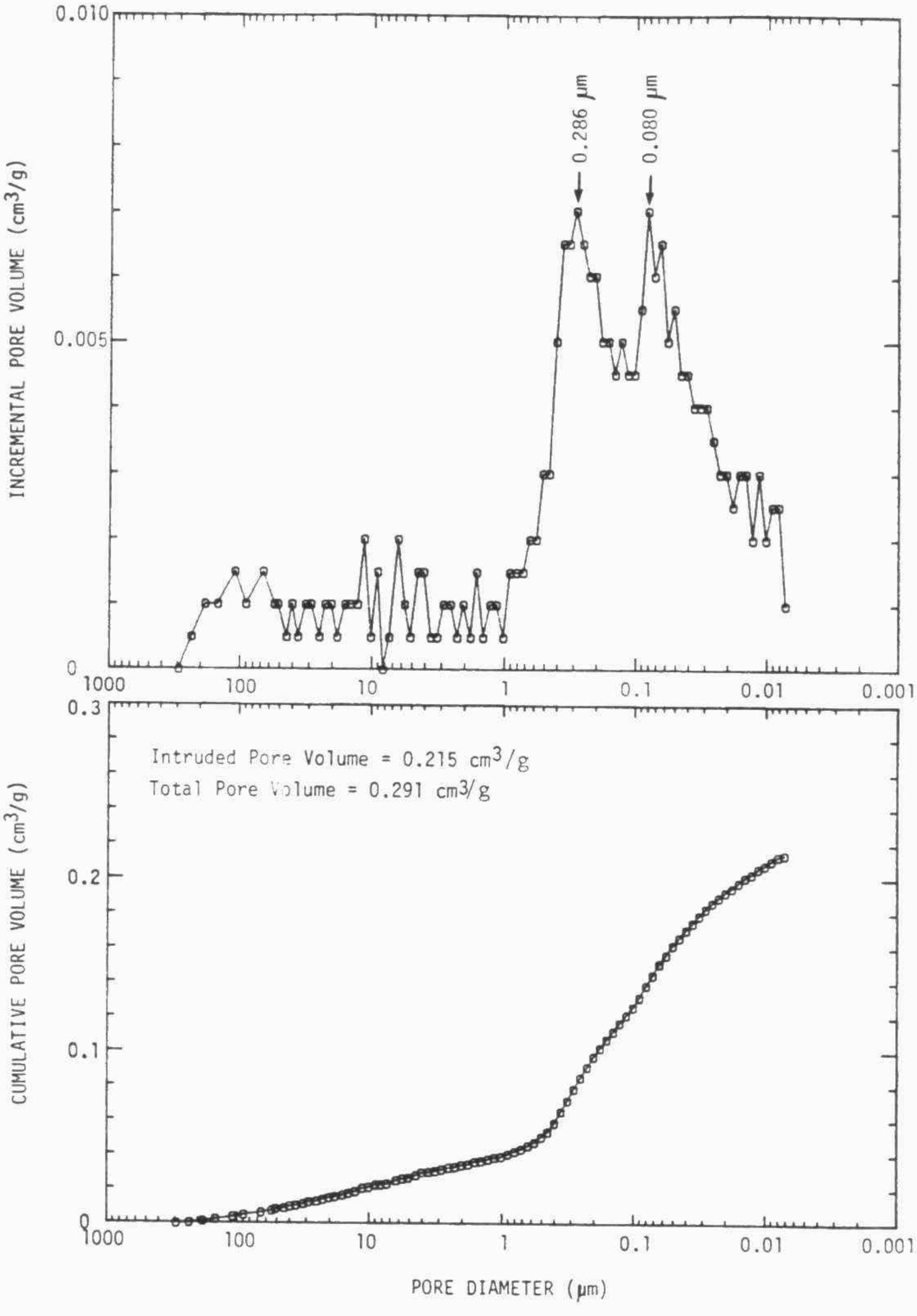

FIGURE J.7 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 80% ETHANOL - 20% WATER

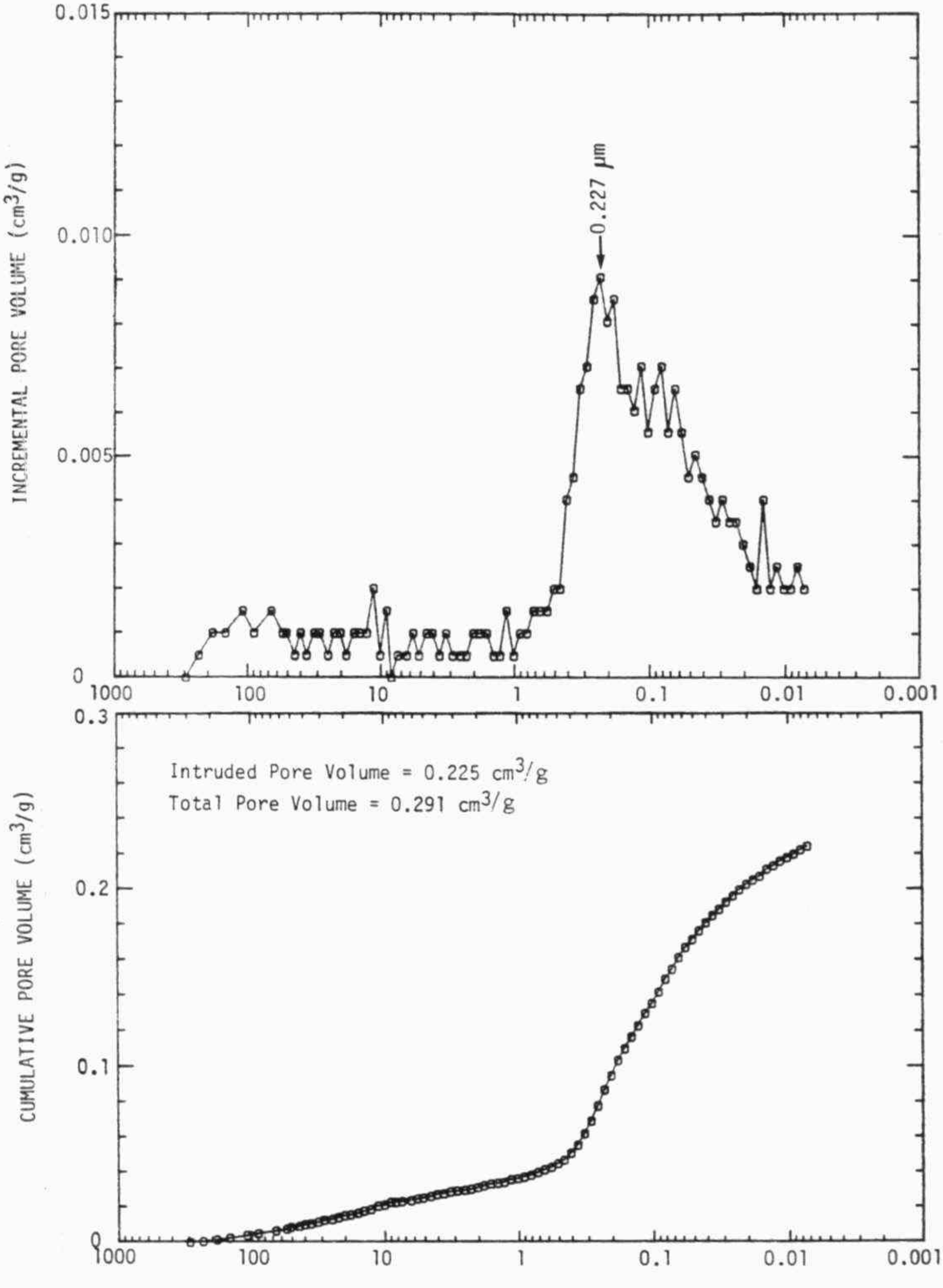

FIGURE J.8 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 90% ETHANOL - 10% WATER

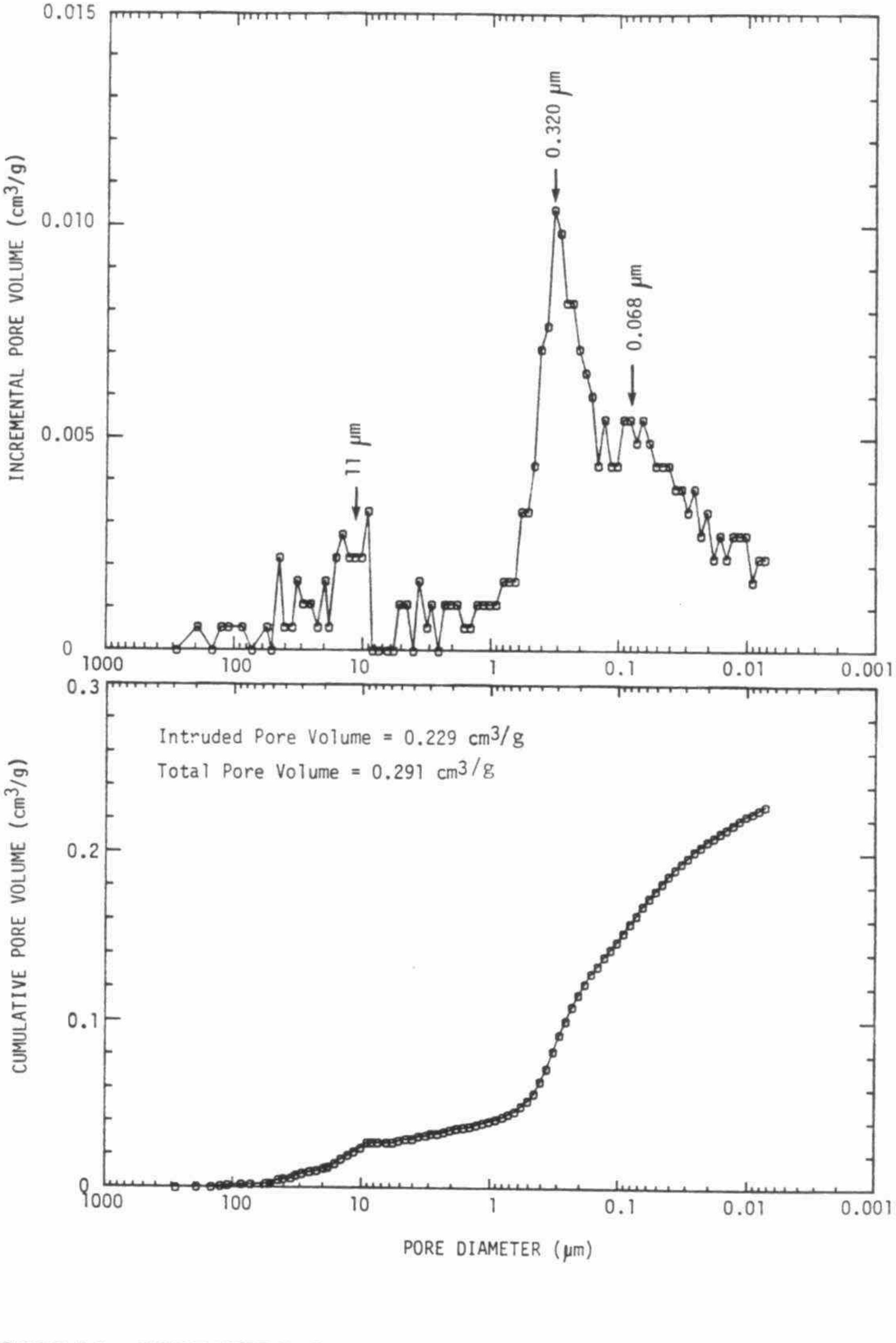

FIGURE J.9 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 100% ETHANOL

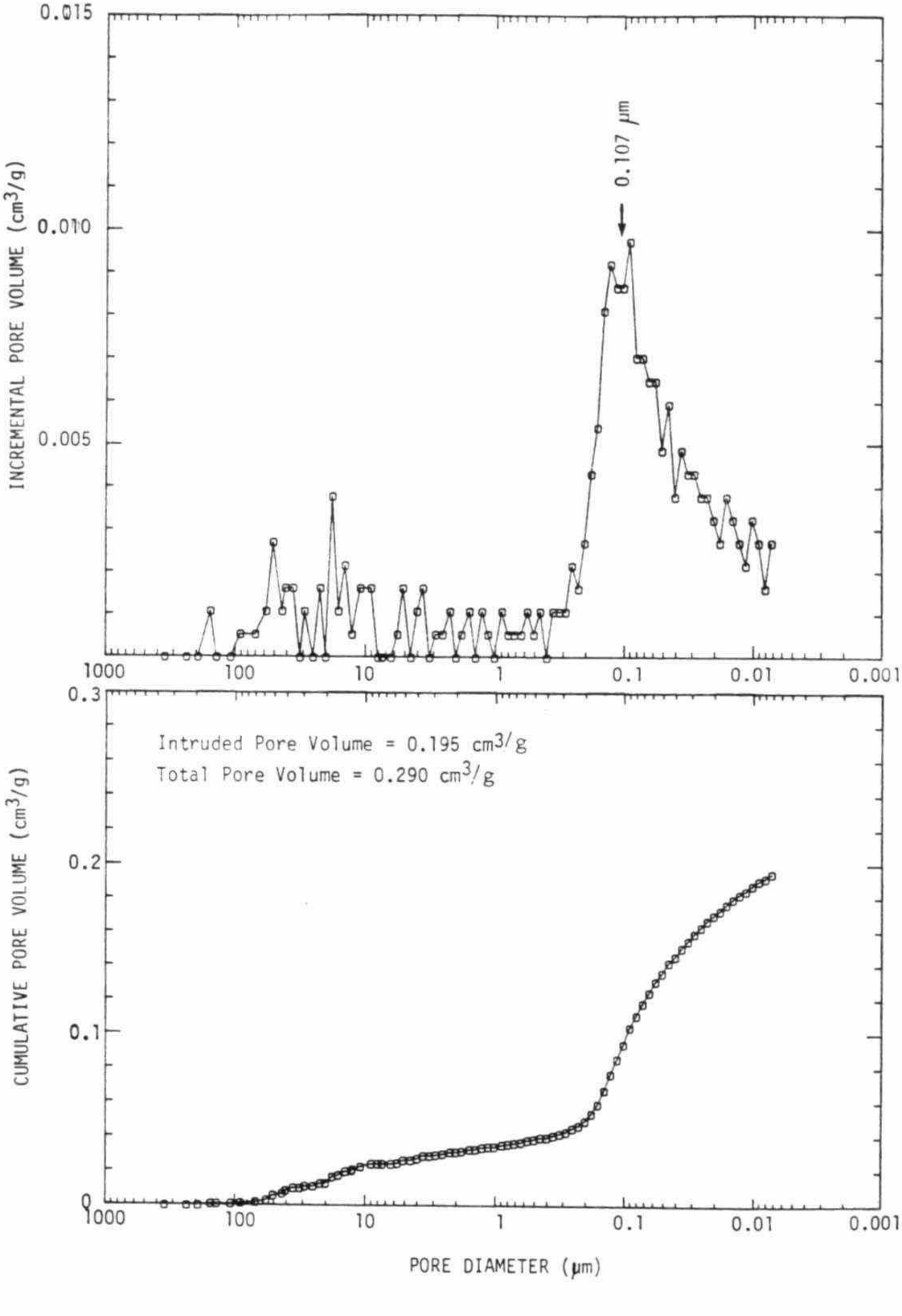

FIGURE J.10 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 100% LEACHATE

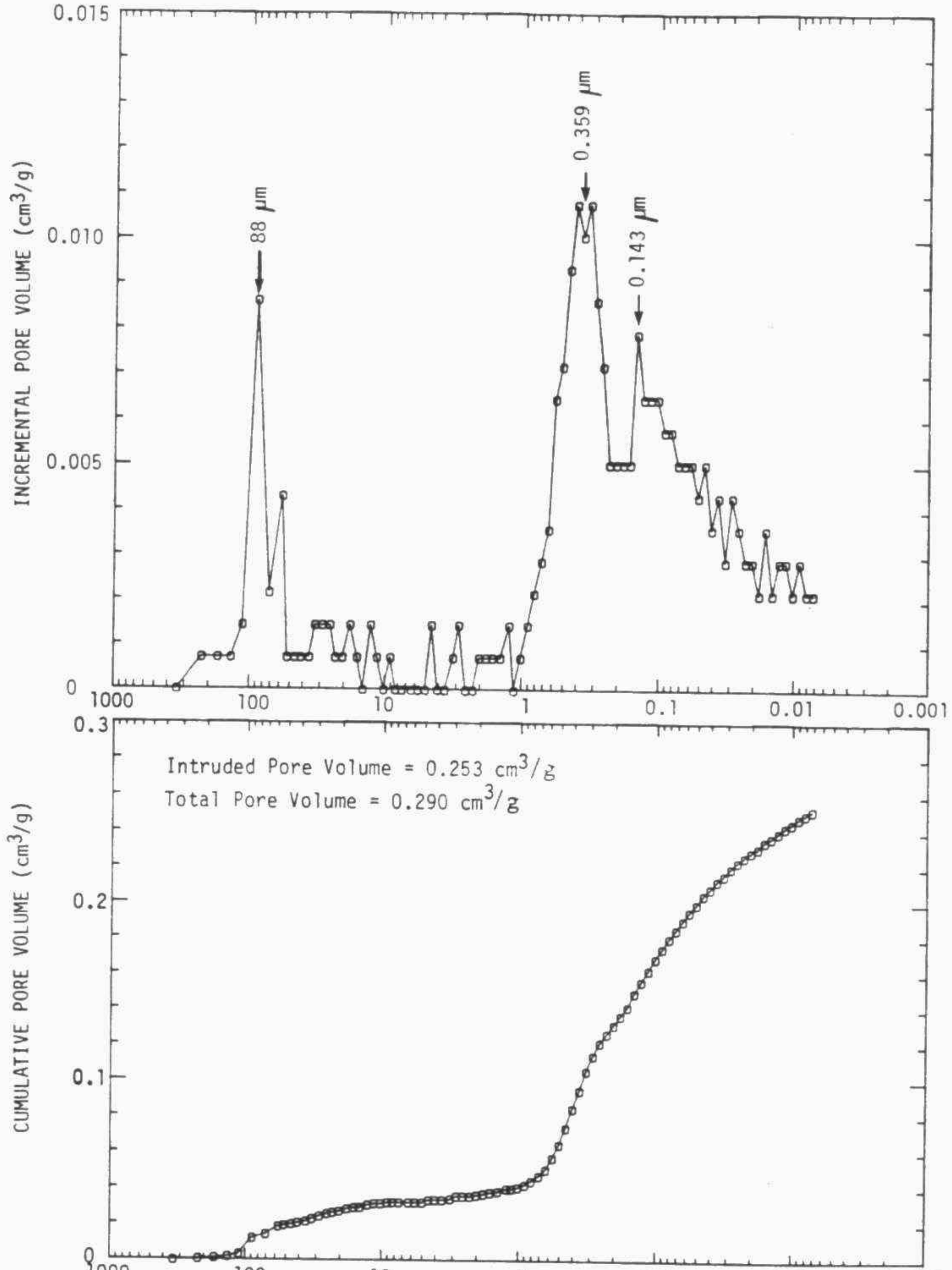

FIGURE J.11 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 10% ETHANOL - 90%LEACHATE

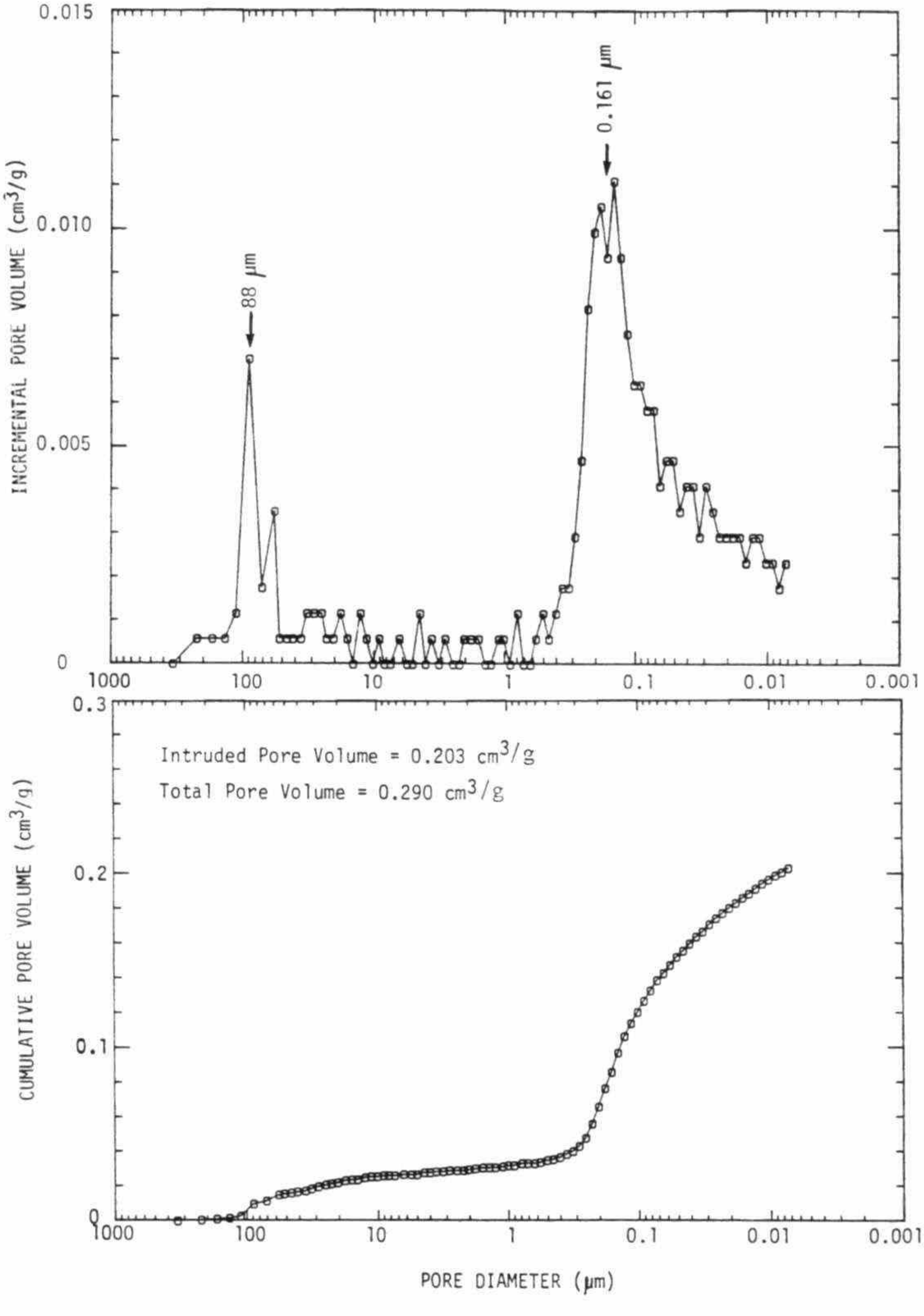

FIGURE J.12 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 20% ETHANOL - 80%LEACHATE

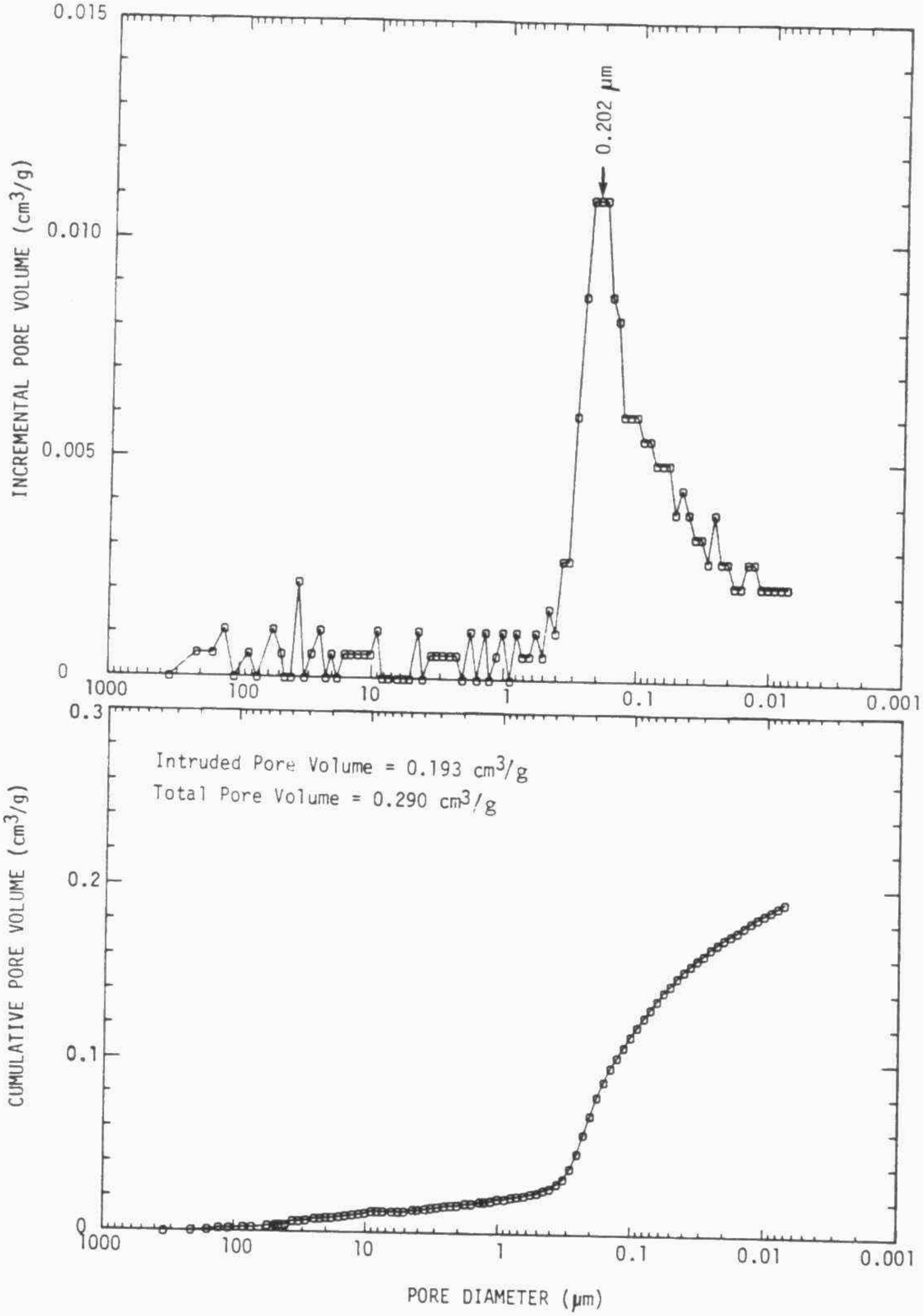

FIGURE J.13 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 35% ETHANOL - 65%LEACHATE

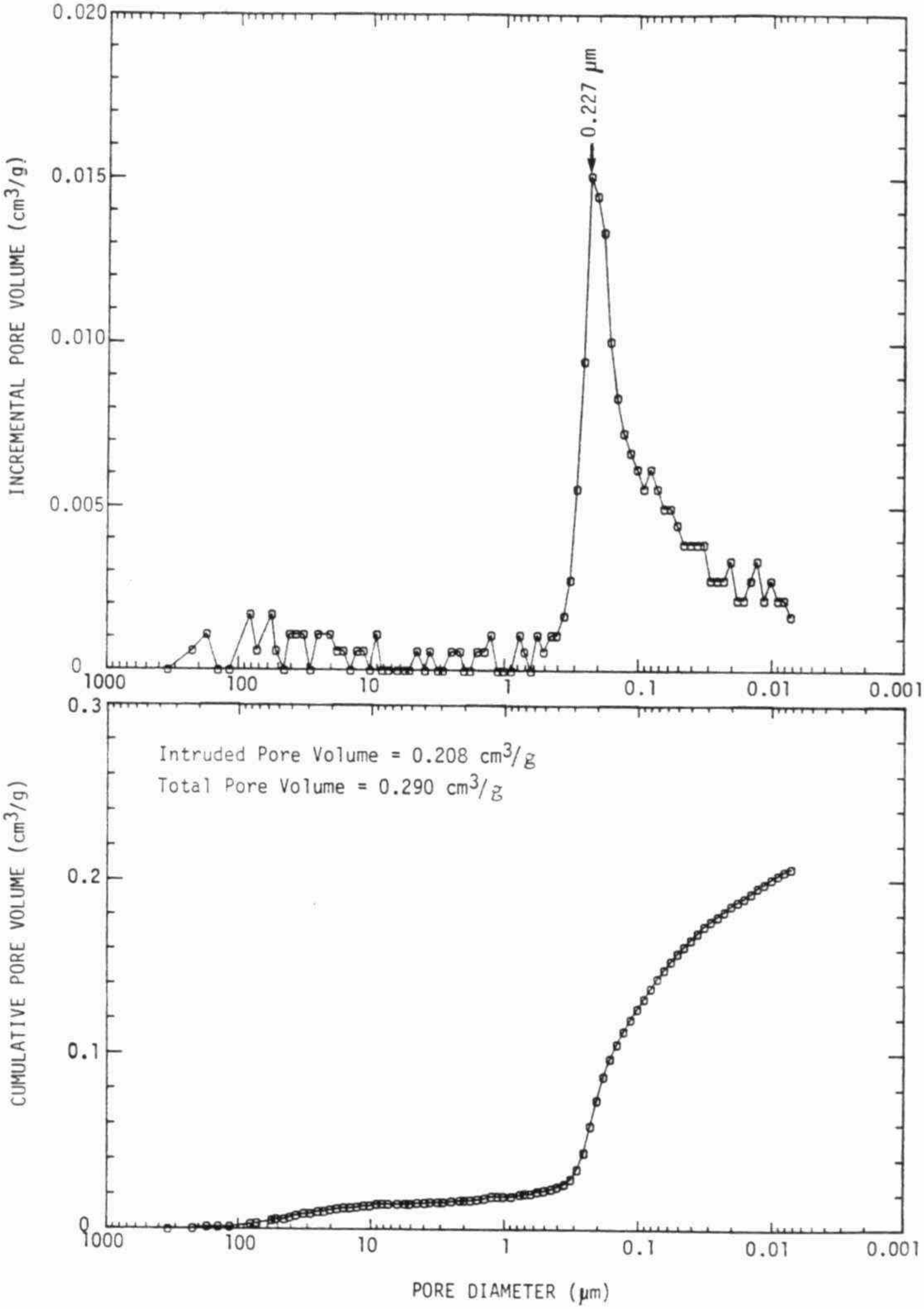

FIGURE J.14 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 50% ETHANOL - 50% LEACHATE

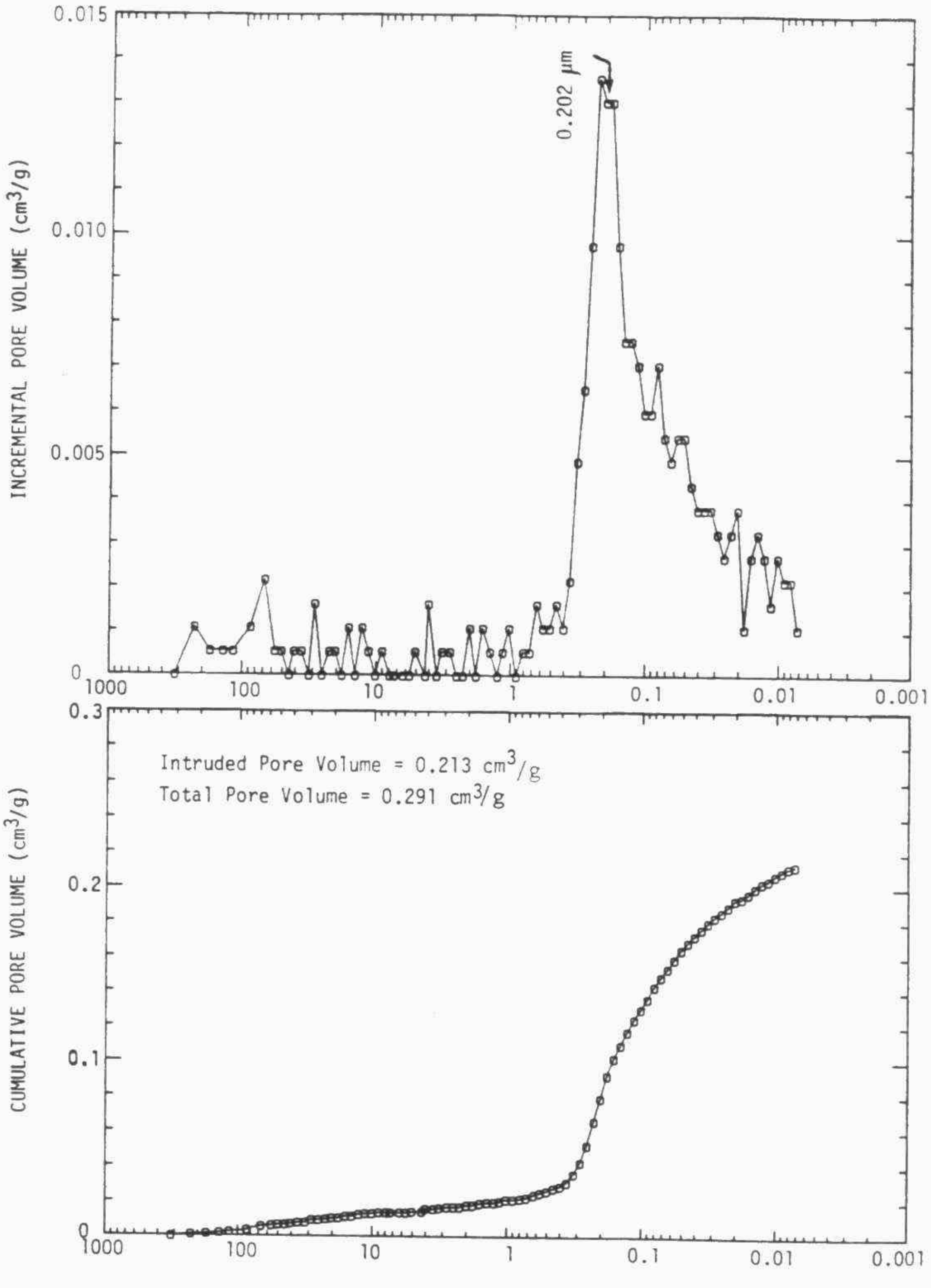

FIGURE J.15 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 65% ETHANOL - 35% LEACHATE

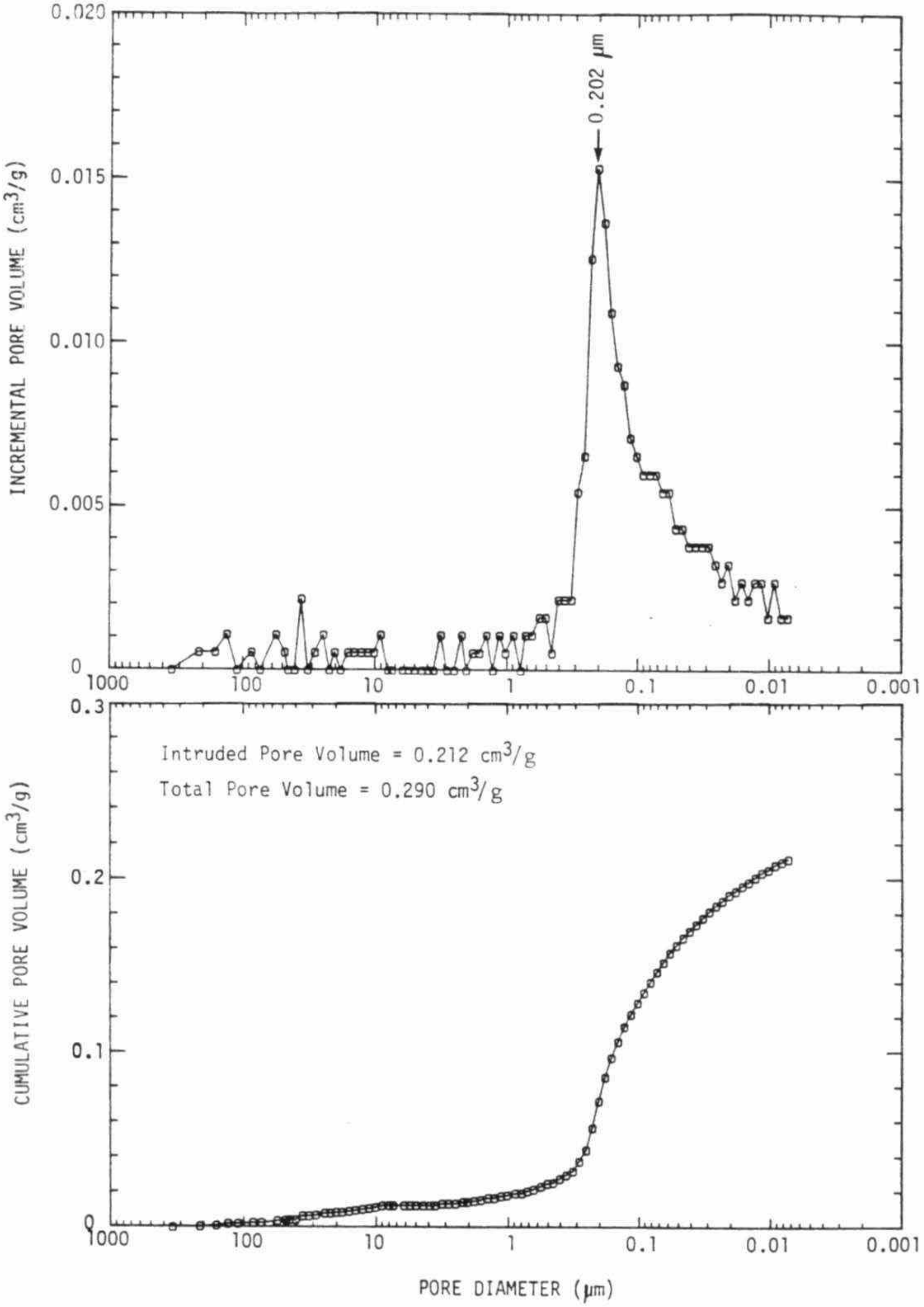

FIGURE J.16 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 80% ETHANOL - 20% LEACHATE

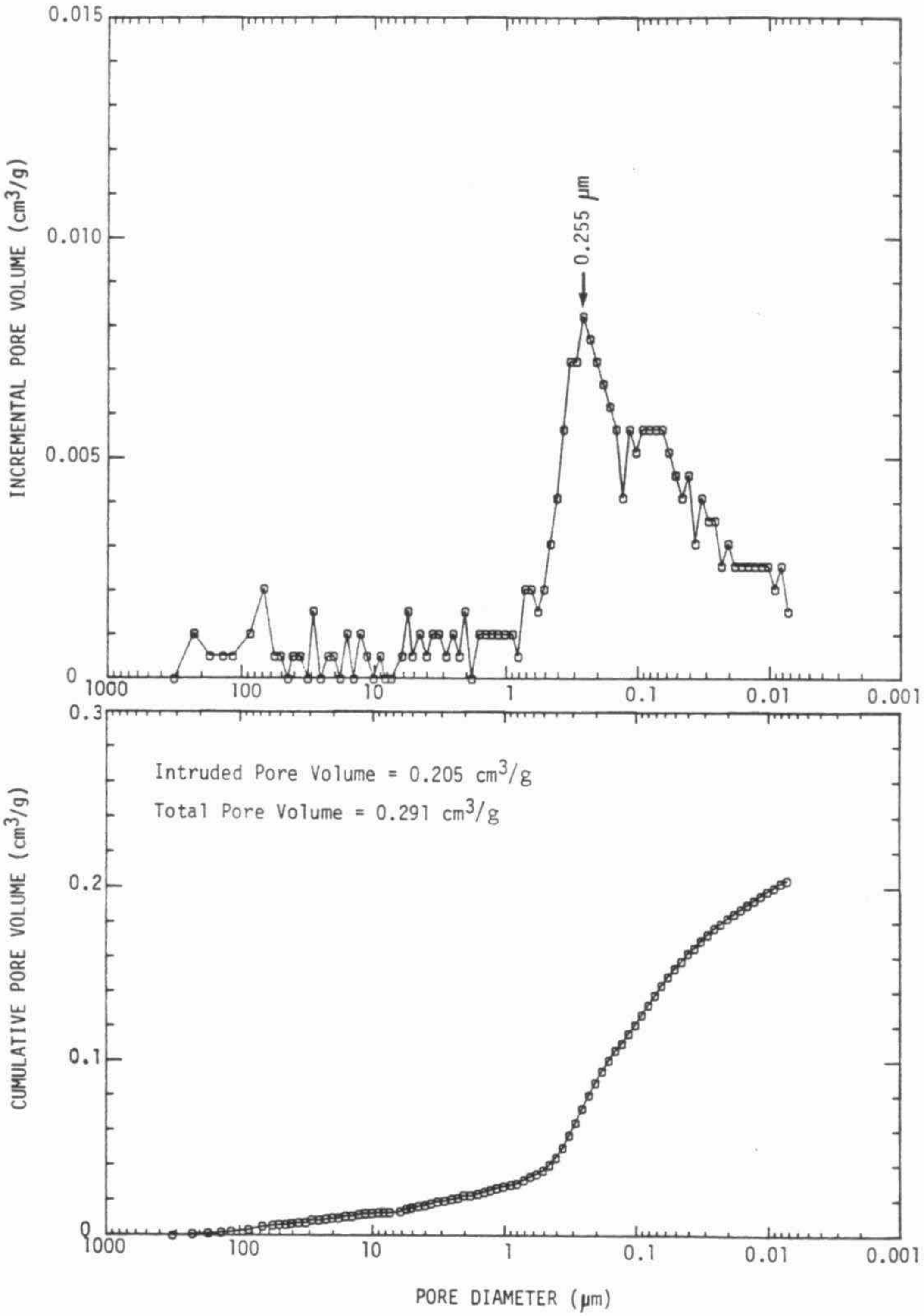

FIGURE J.17 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 90% ETHANOL - 10% LEACHATE

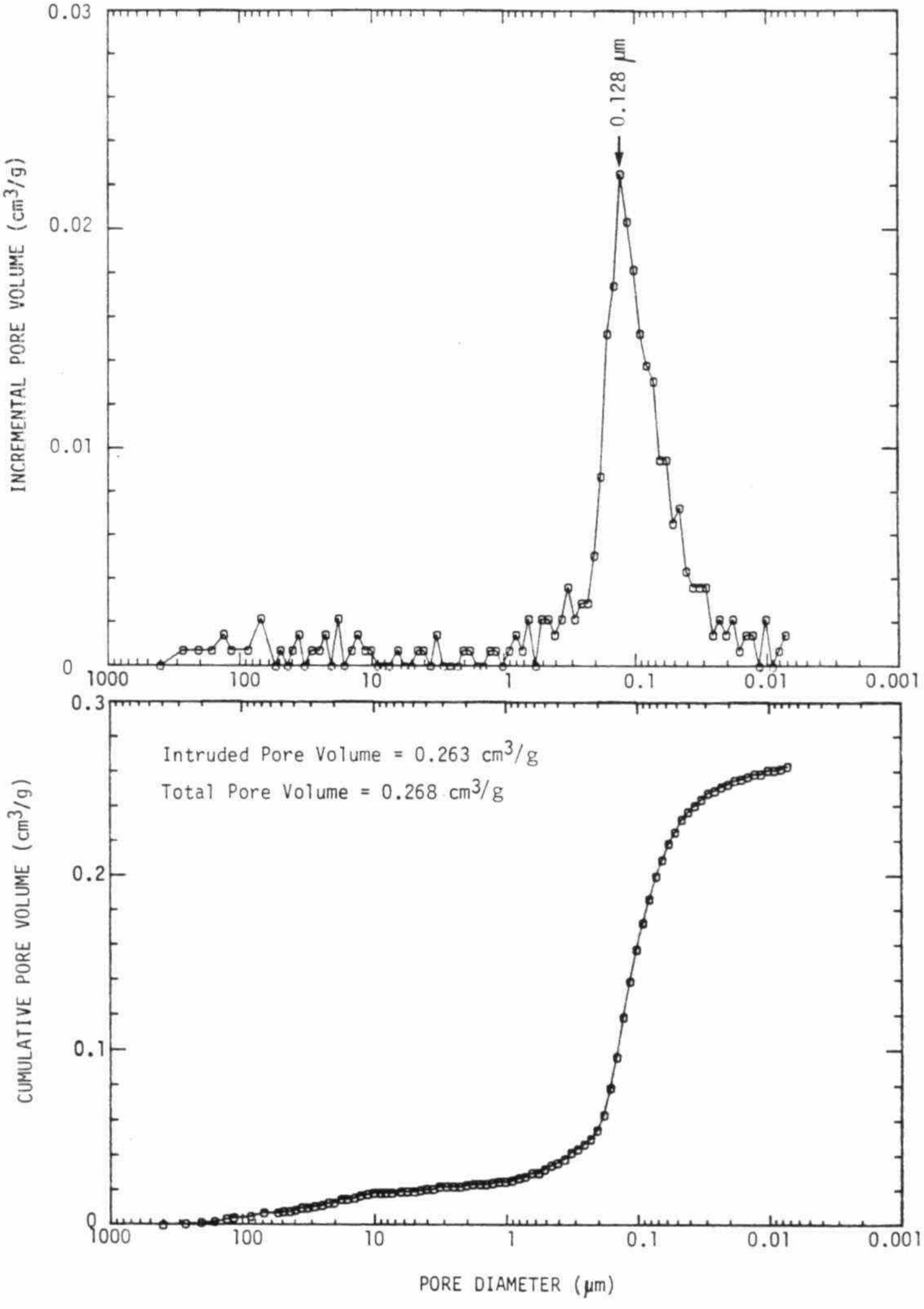

FIGURE J.18 PORE SIZE DISTRIBUTION FOR KAOLINITE MIXED WITH 100% WATER

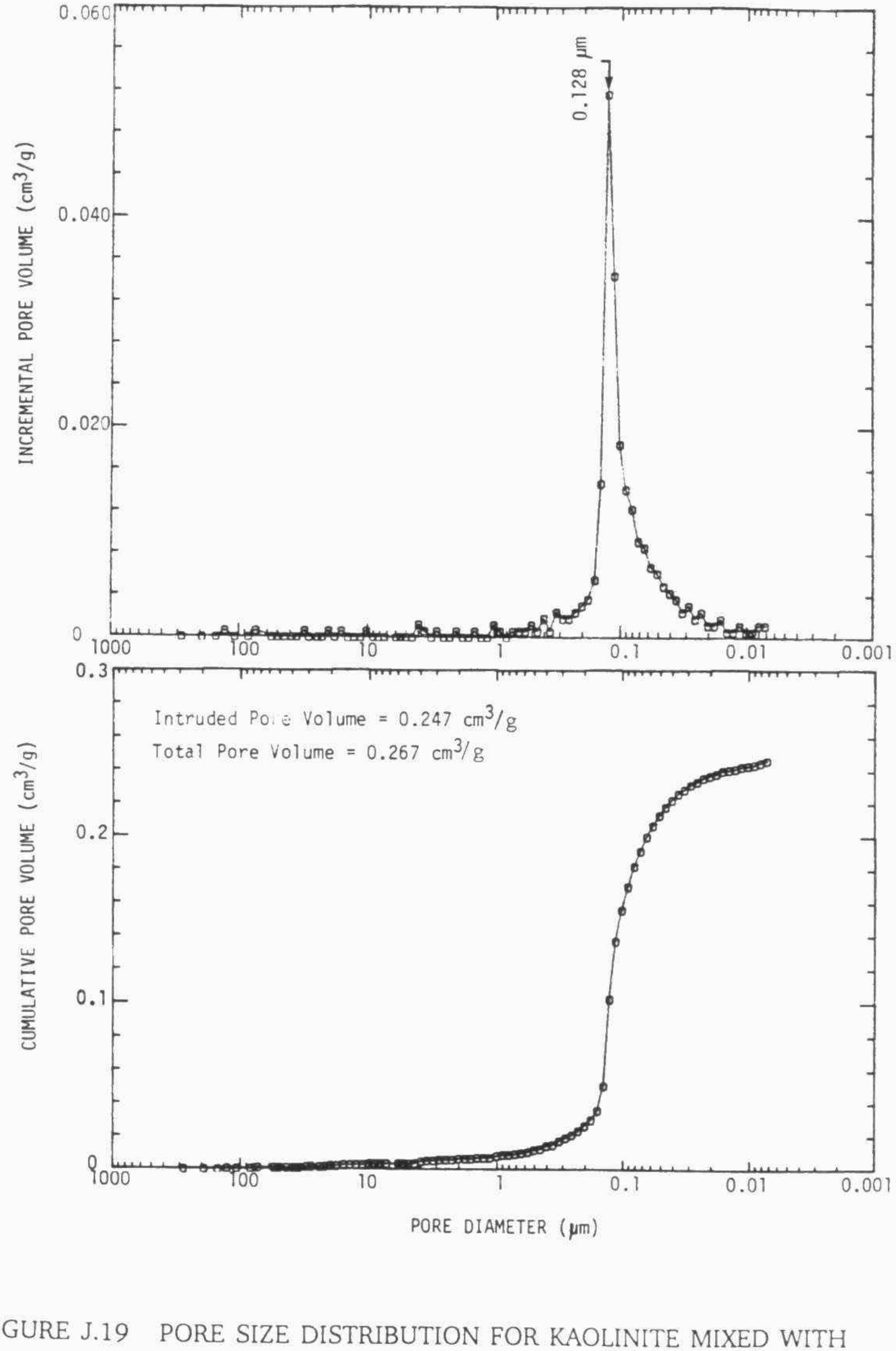

FIGURE J.19 PORE SIZE DISTRIBUTION FOR KAOLINITE MIXED WITH 20% ETHANOL - 80% WATER

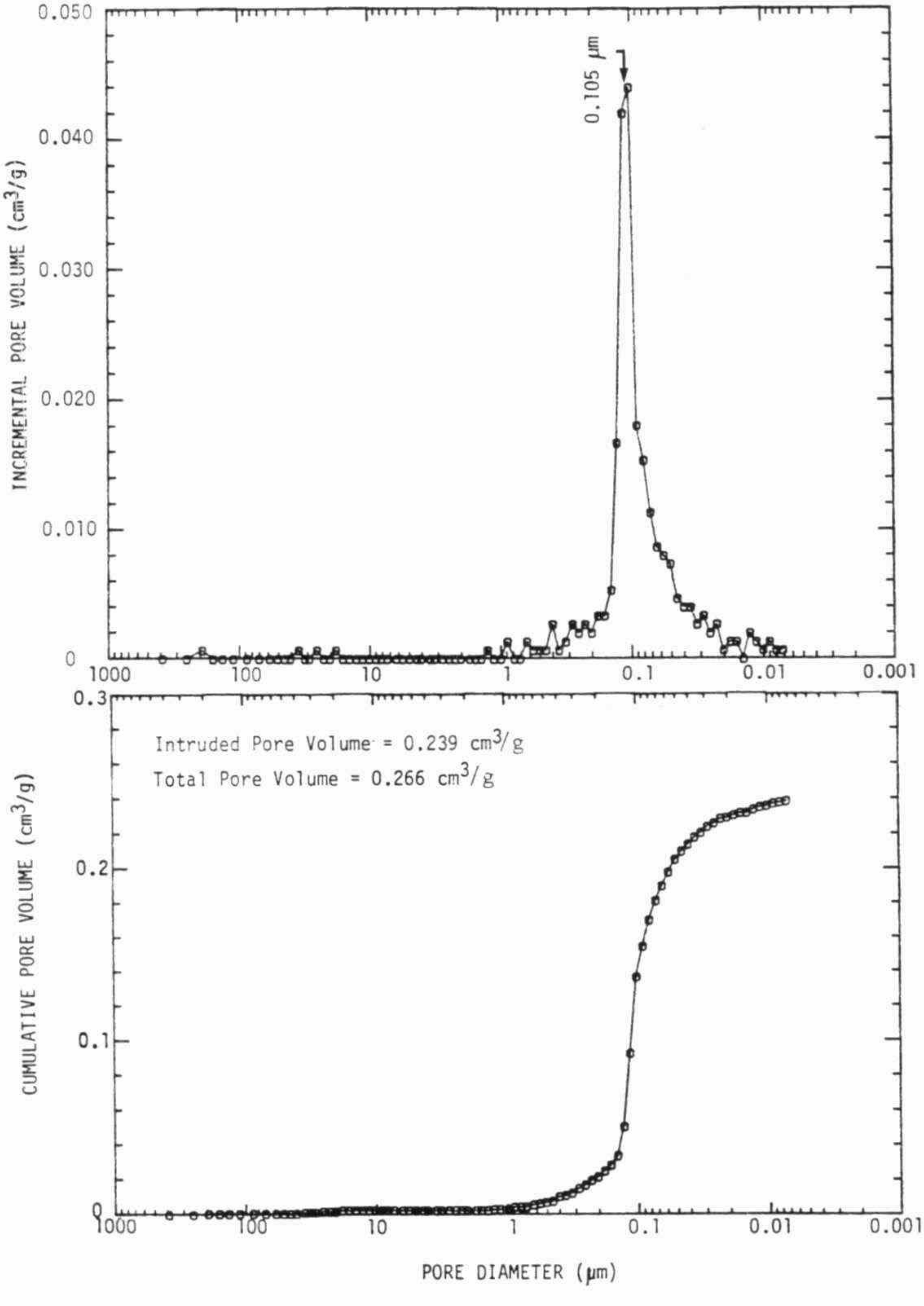

FIGURE J.20 PORE SIZE DISTRIBUTION FOR KAOLINITE MIXED WITH 50% ETHANOL - 50% WATER

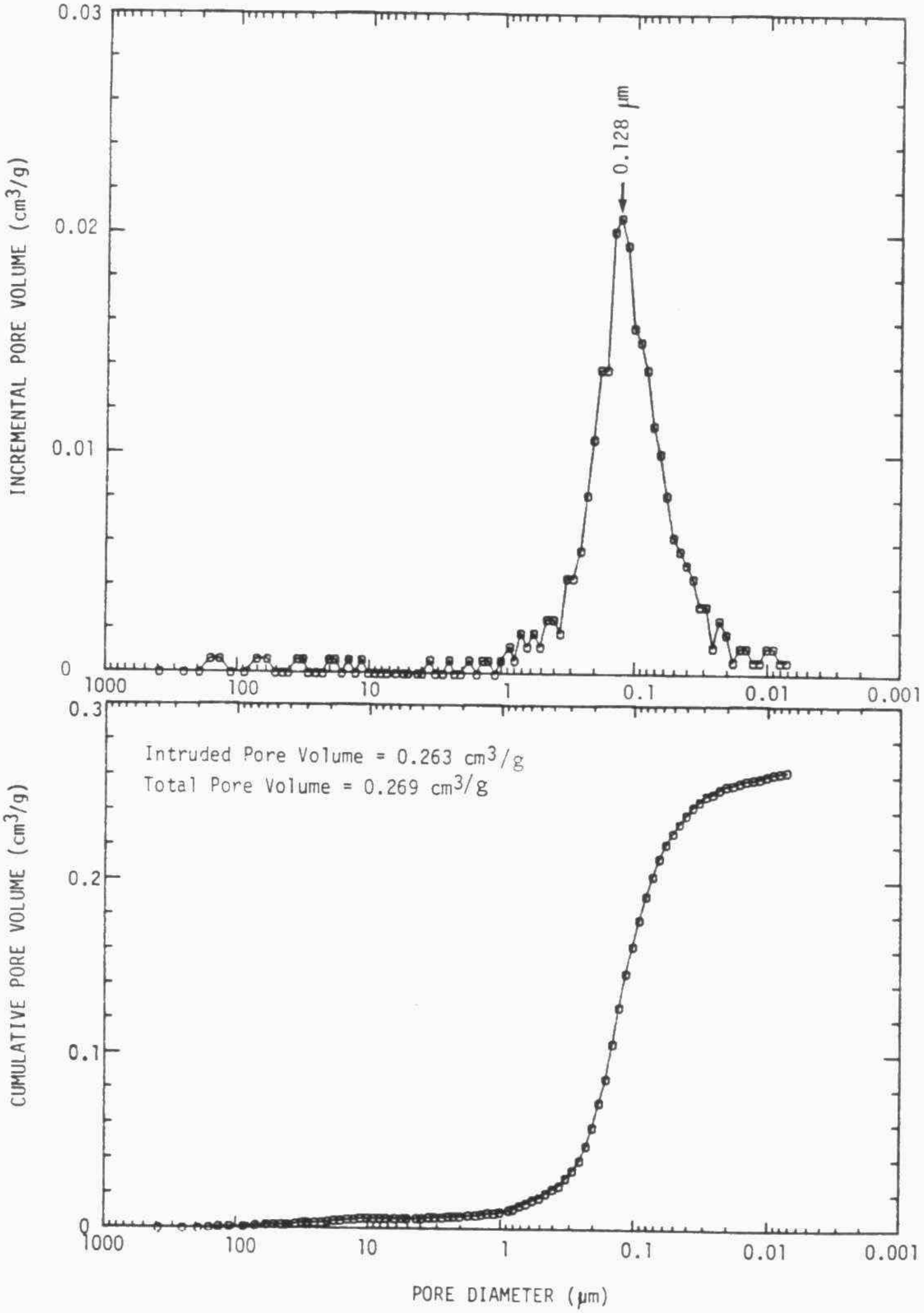

FIGURE J.21 PORE SIZE DISTRIBUTION FOR KAOLINITE MIXED WITH 80% ETHANOL - 20% WATER

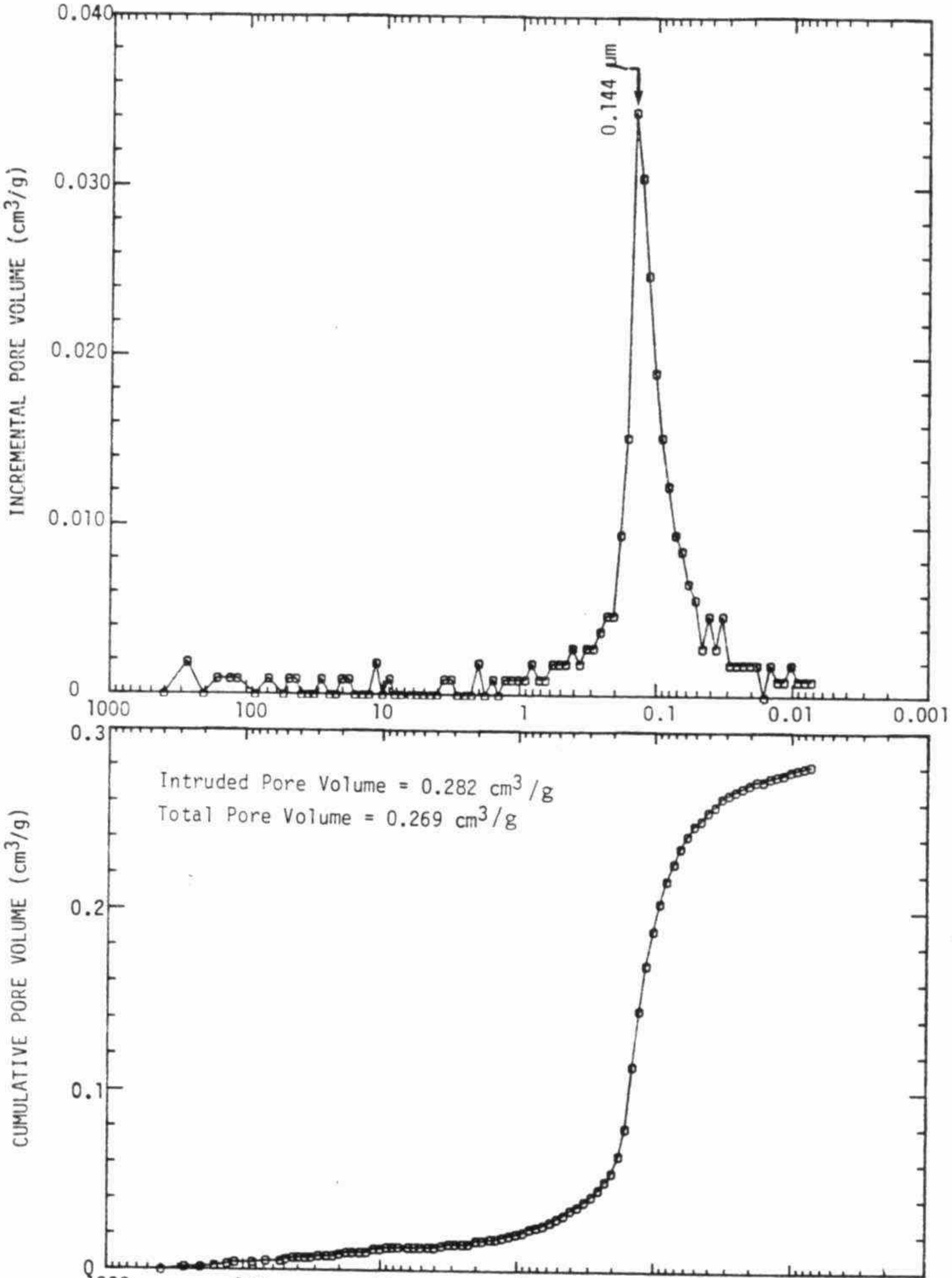

FIGURE J.22 PORE SIZE DISTRIBUTION FOR KAOLINITE MIXED WITH 100% ETHANOL

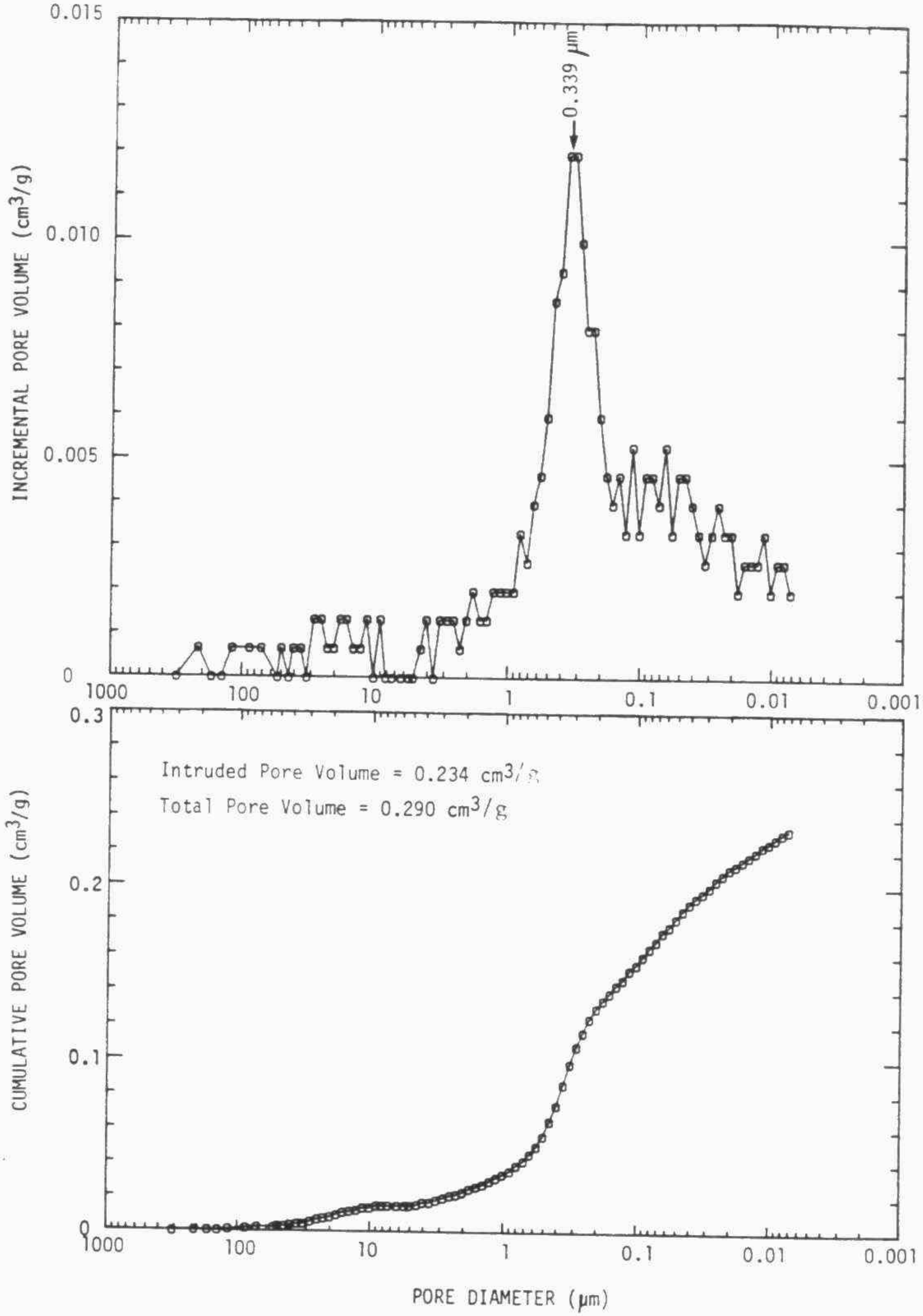

FIGURE J.23 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 20% DIOXANE - 80% WATER

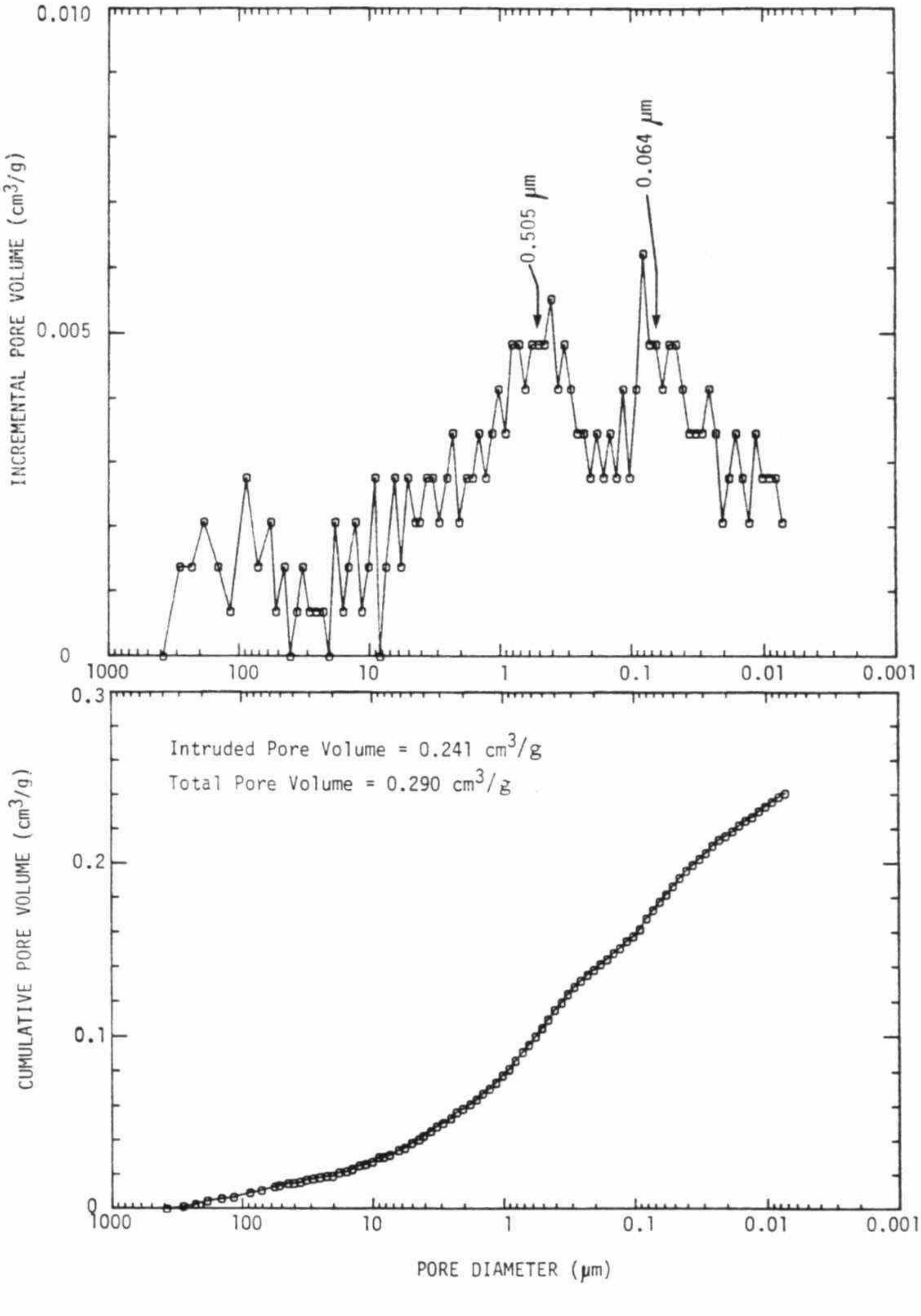

FIGURE J.24 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 50% DIOXANE - 50% WATER

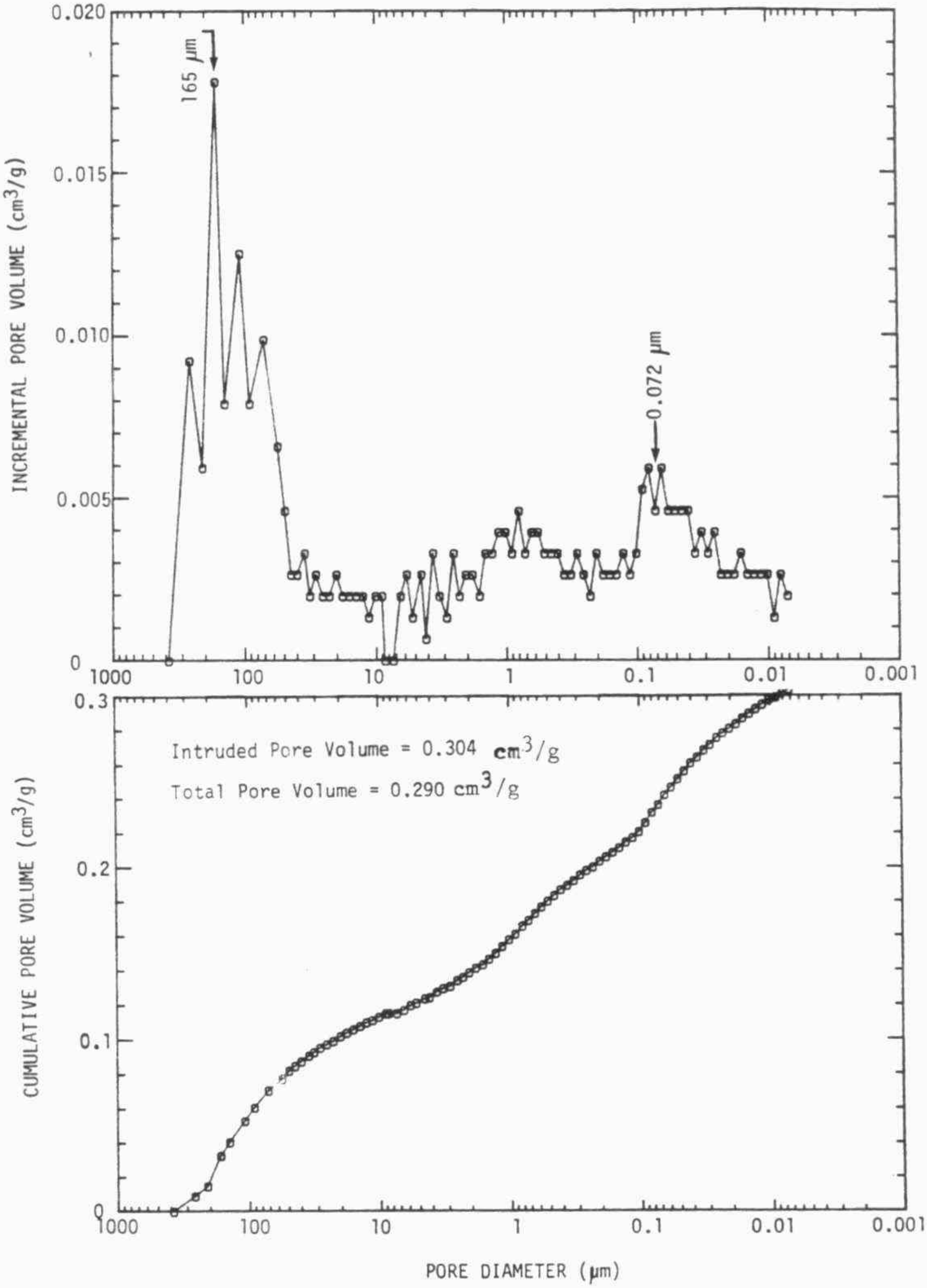

FIGURE J.25 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 80% DIOXANE - 20% WATER

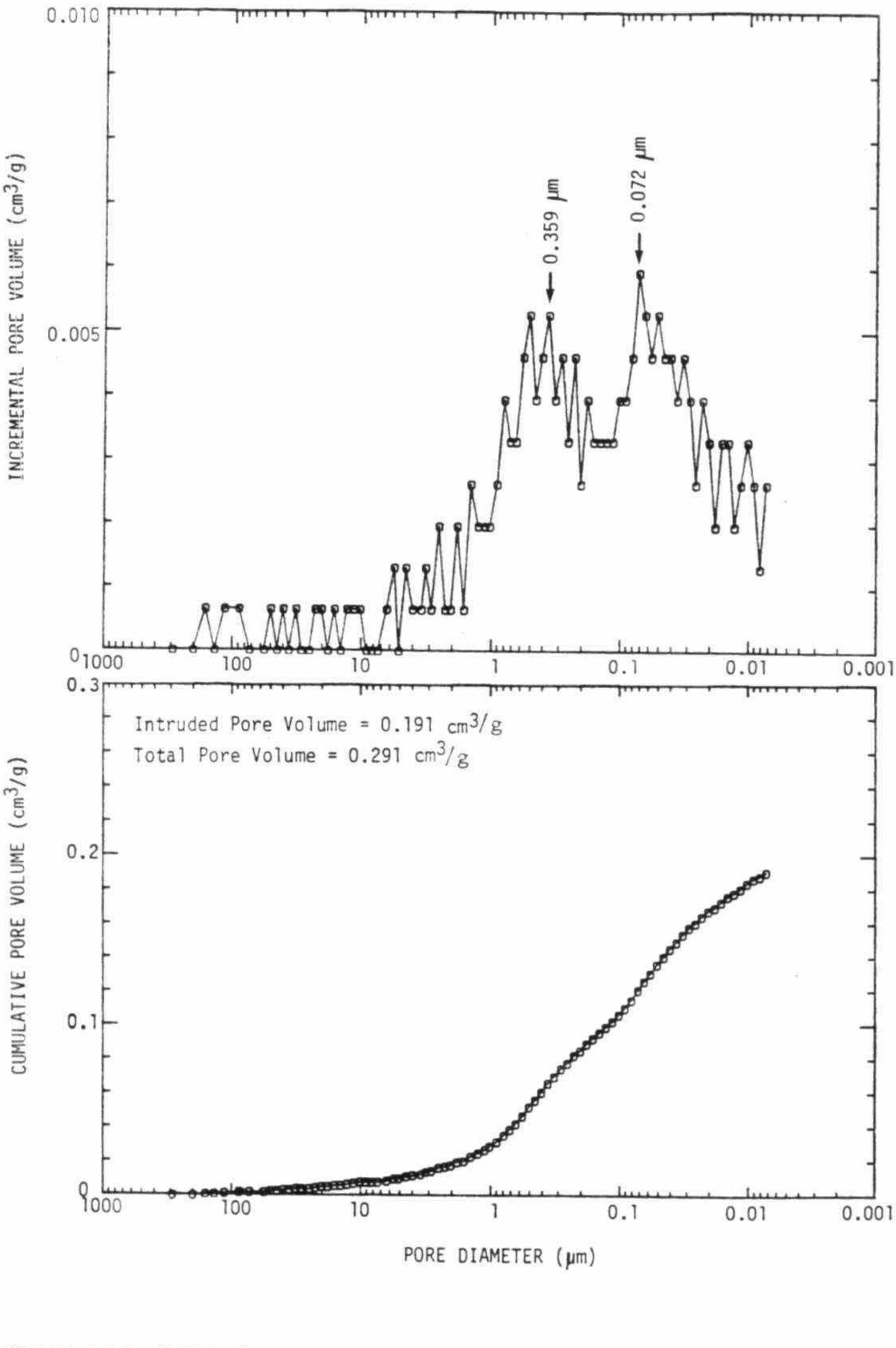

FIGURE J.26 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 100% DIOXANE

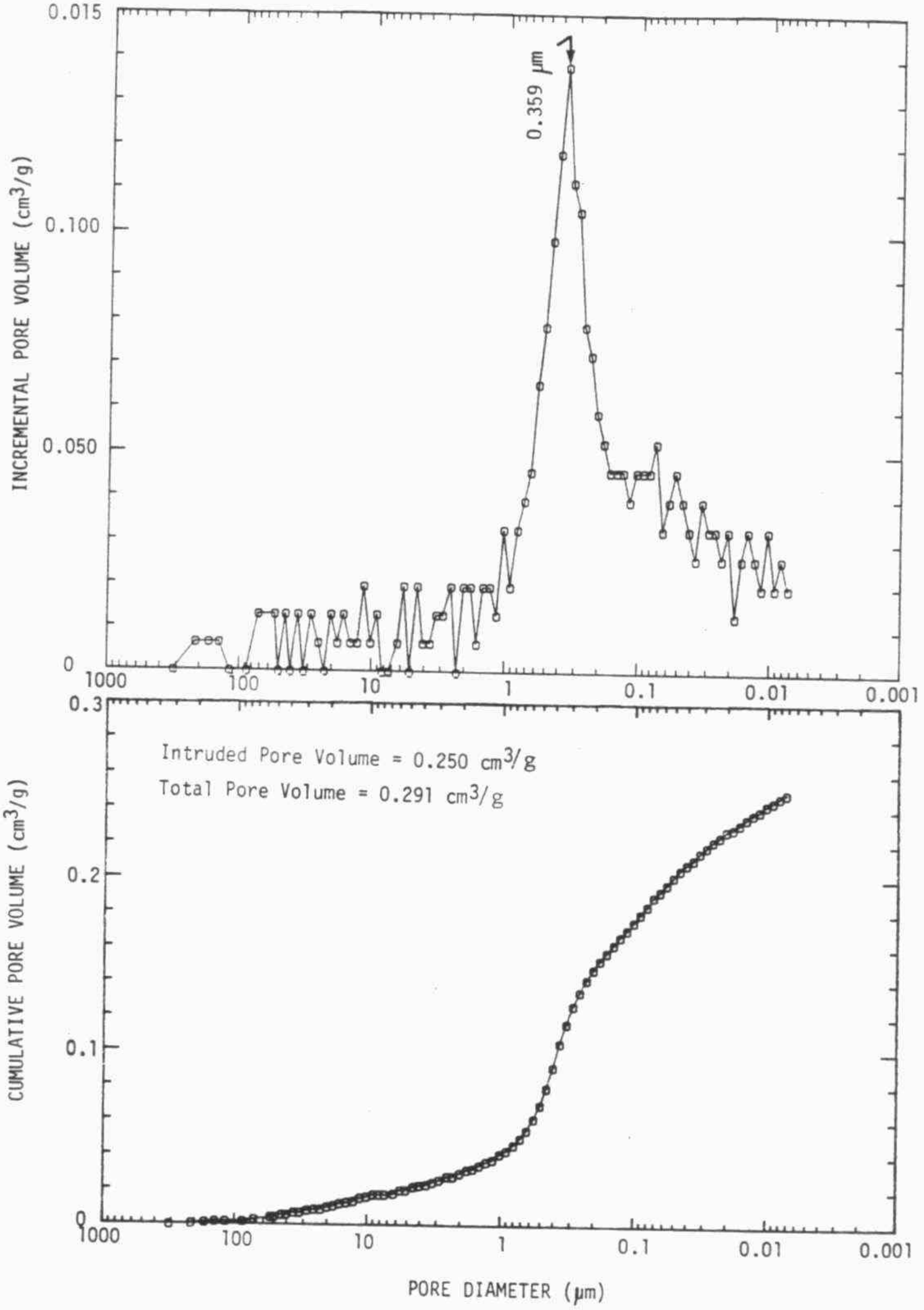

FIGURE J.27 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 20% DIOXANE - 80% LEACHATE

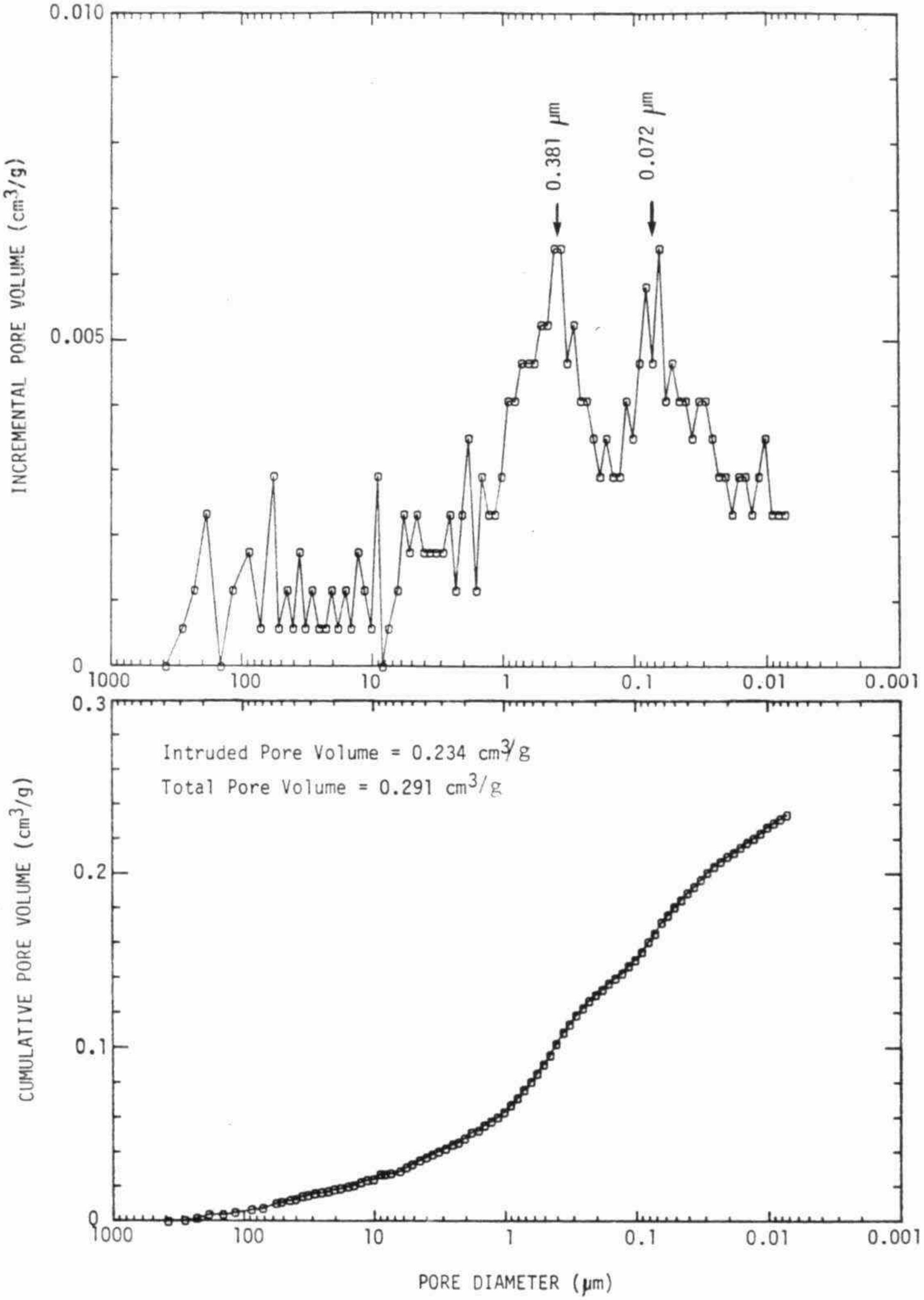

FIGURE J.28 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 50% DIOXANE - 50% LEACHATE

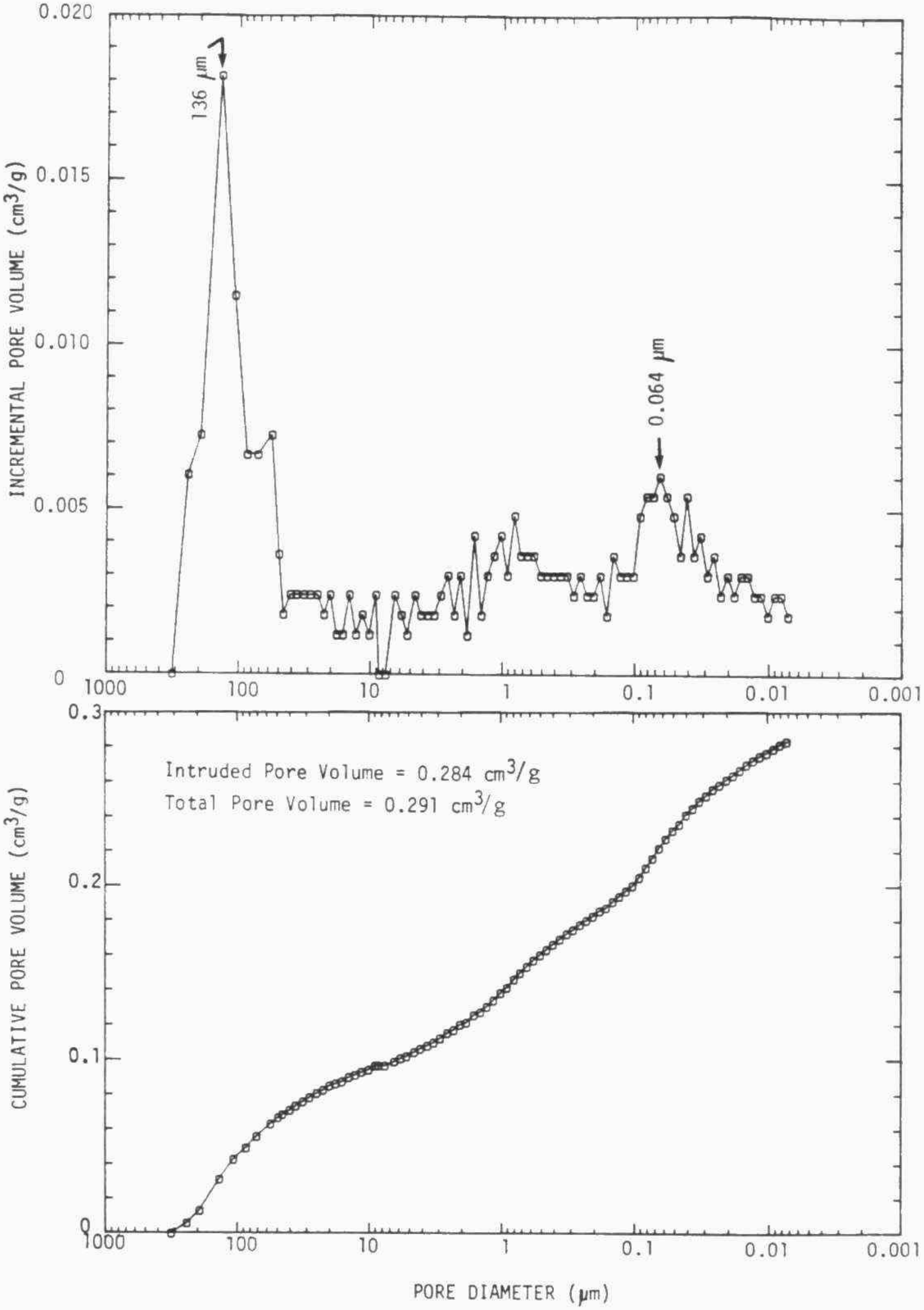

FIGURE J.29 PORE SIZE DISTRIBUTION FOR BROWN SARNIA CLAY MIXED WITH 80% DIOXANE - 20% LEACHATE

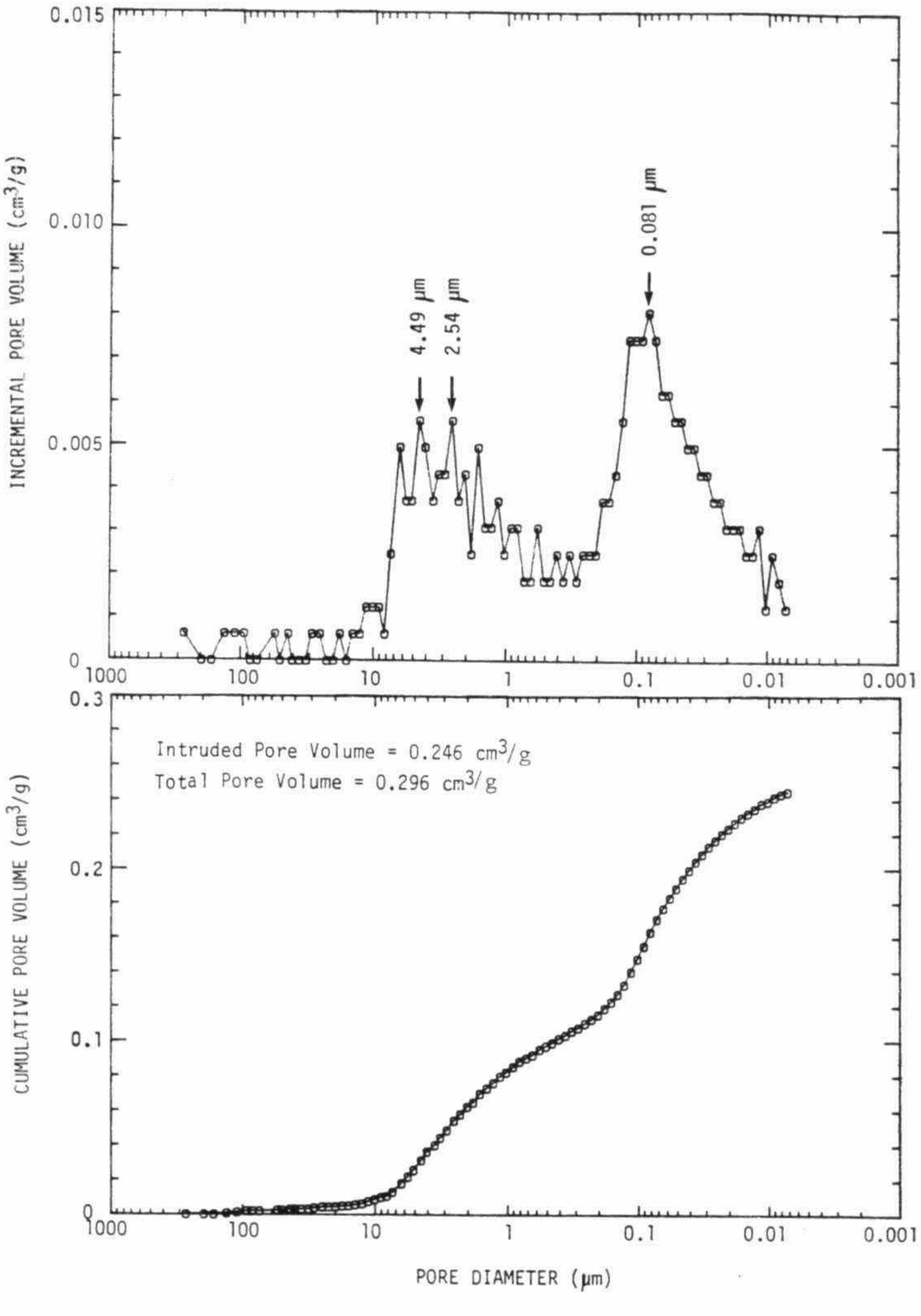

FIGURE J.30 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY

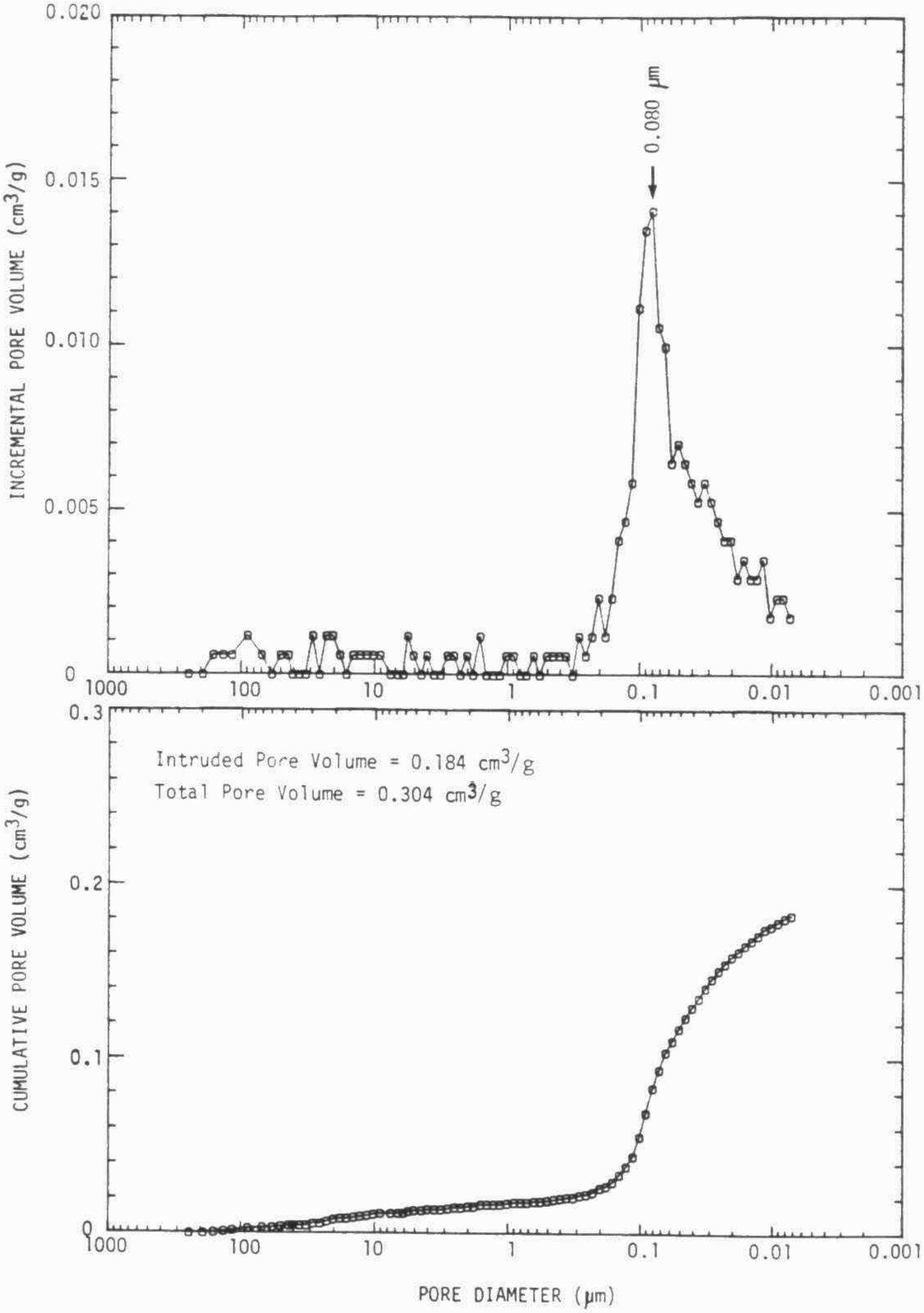

FIGURE J.31 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 20% ETHANOL - 80% LEACHATE

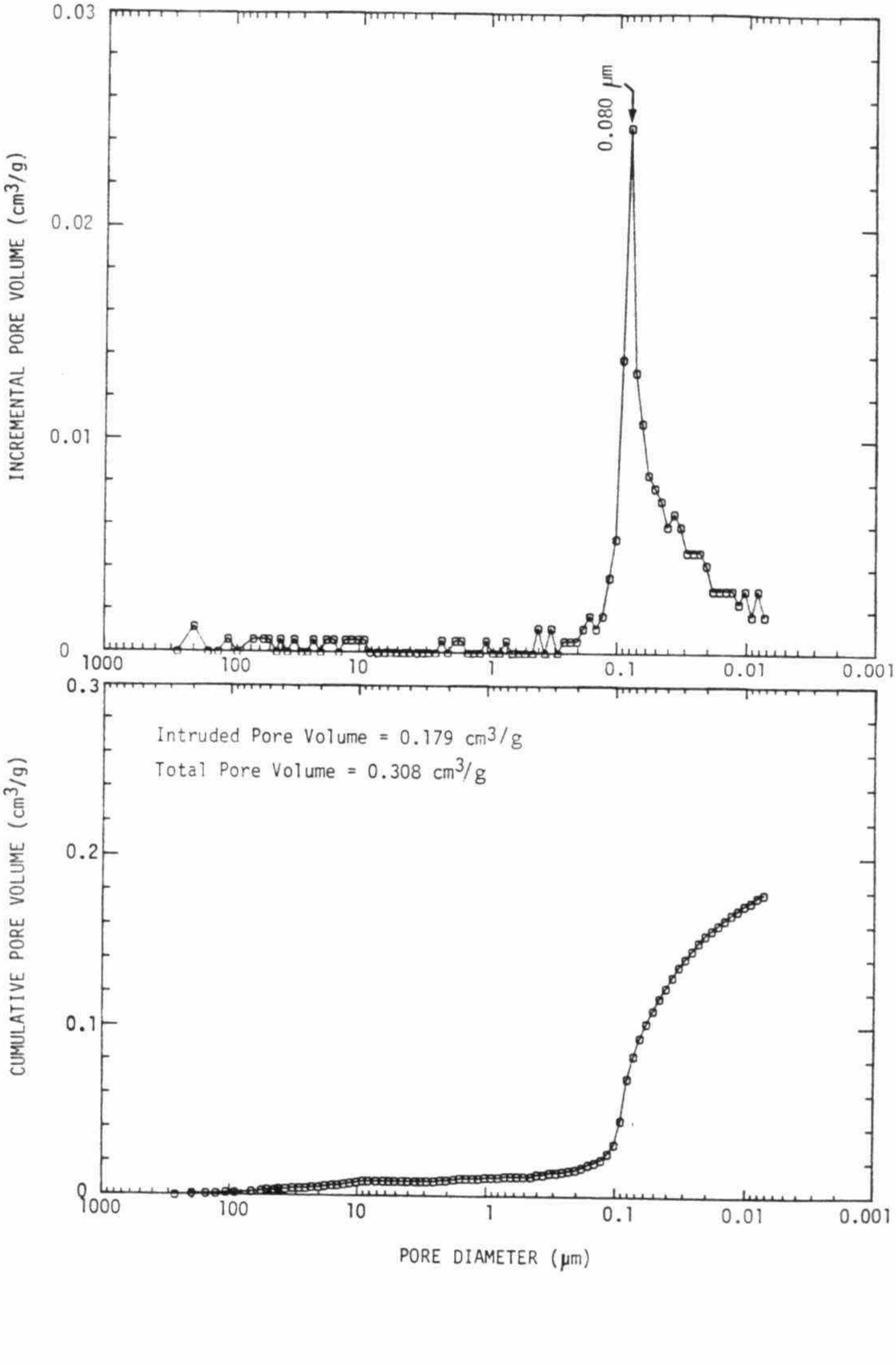

FIGURE J.32 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 40% ETHANOL - 60% LEACHATE

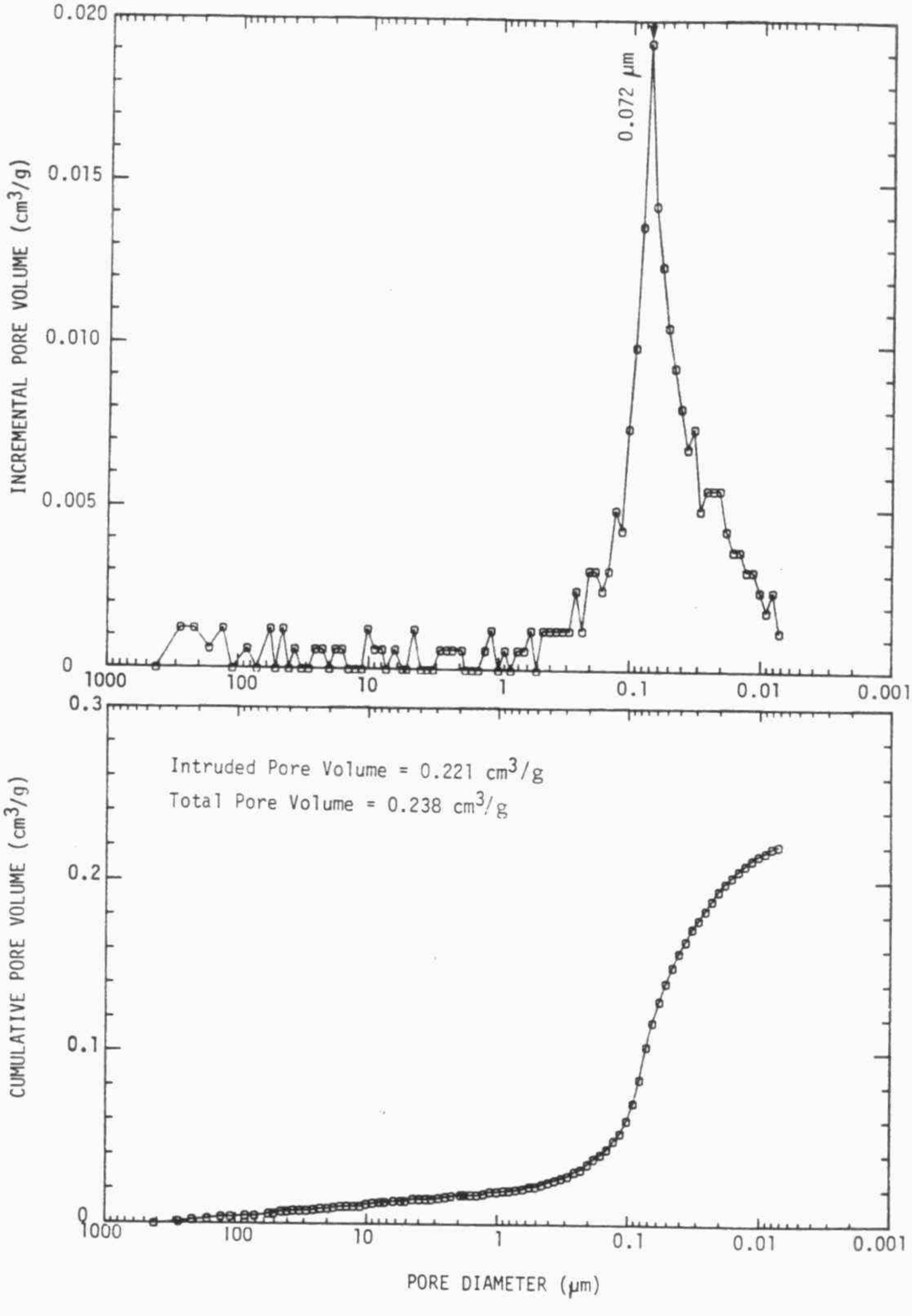

FIGURE J.33 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 100% ETHANOL (σ'_v = 0)

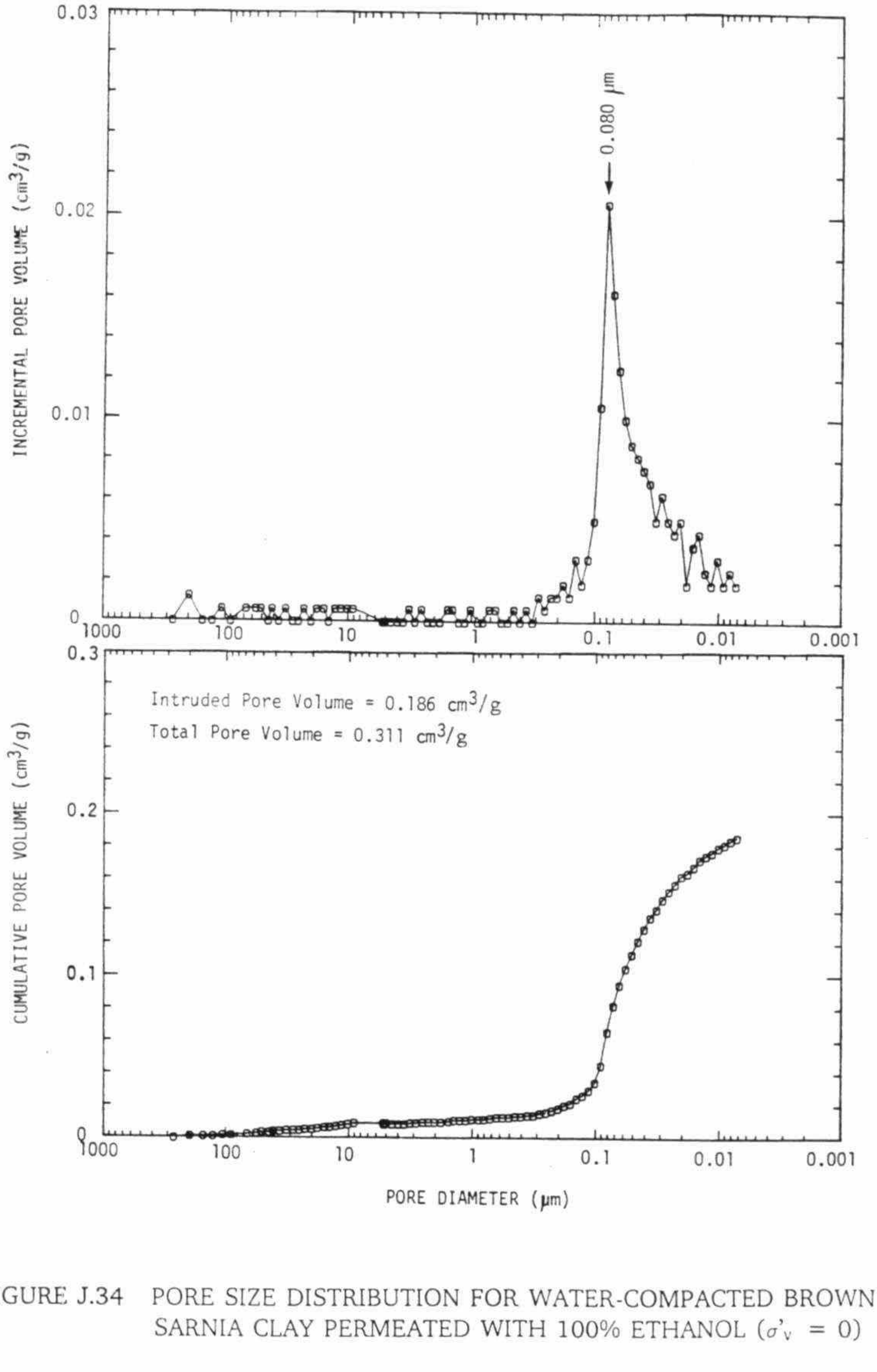

FIGURE J.34 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 100% ETHANOL (σ'_v = 0)

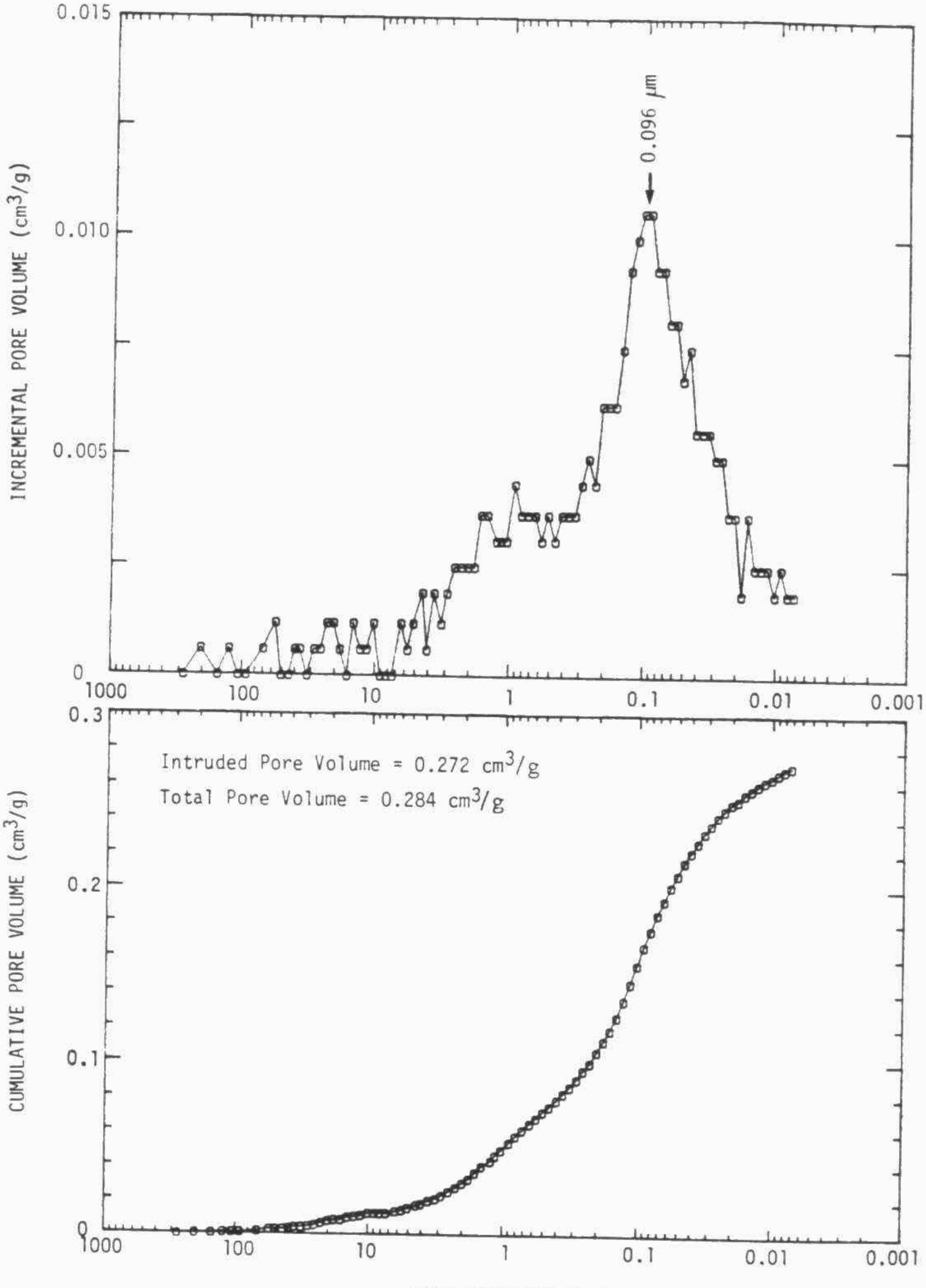

FIGURE J.35 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 10% DIOXANE - 90% LEACHATE

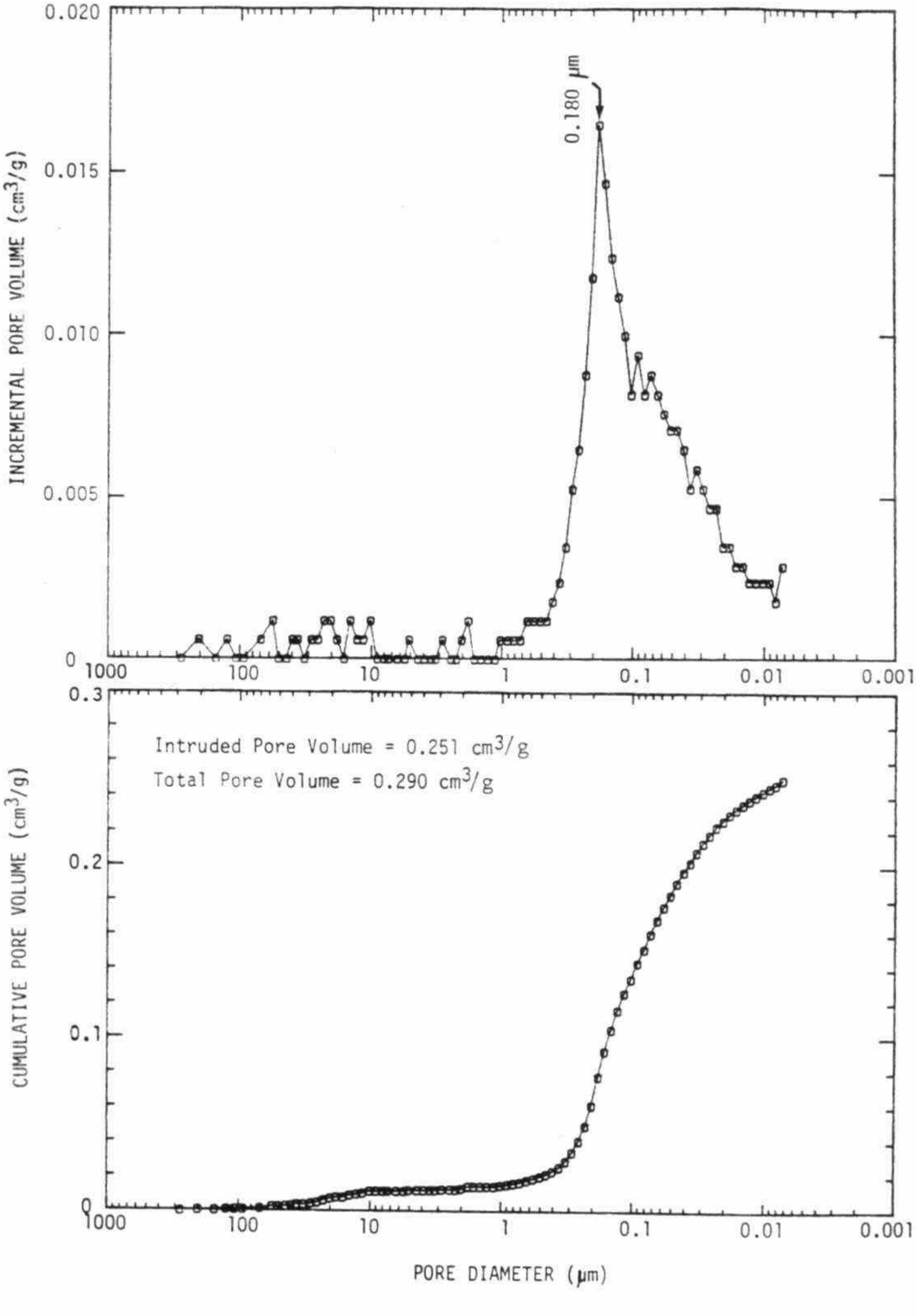

FIGURE J.36 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 20% DIOXANE - 80% LEACHATE

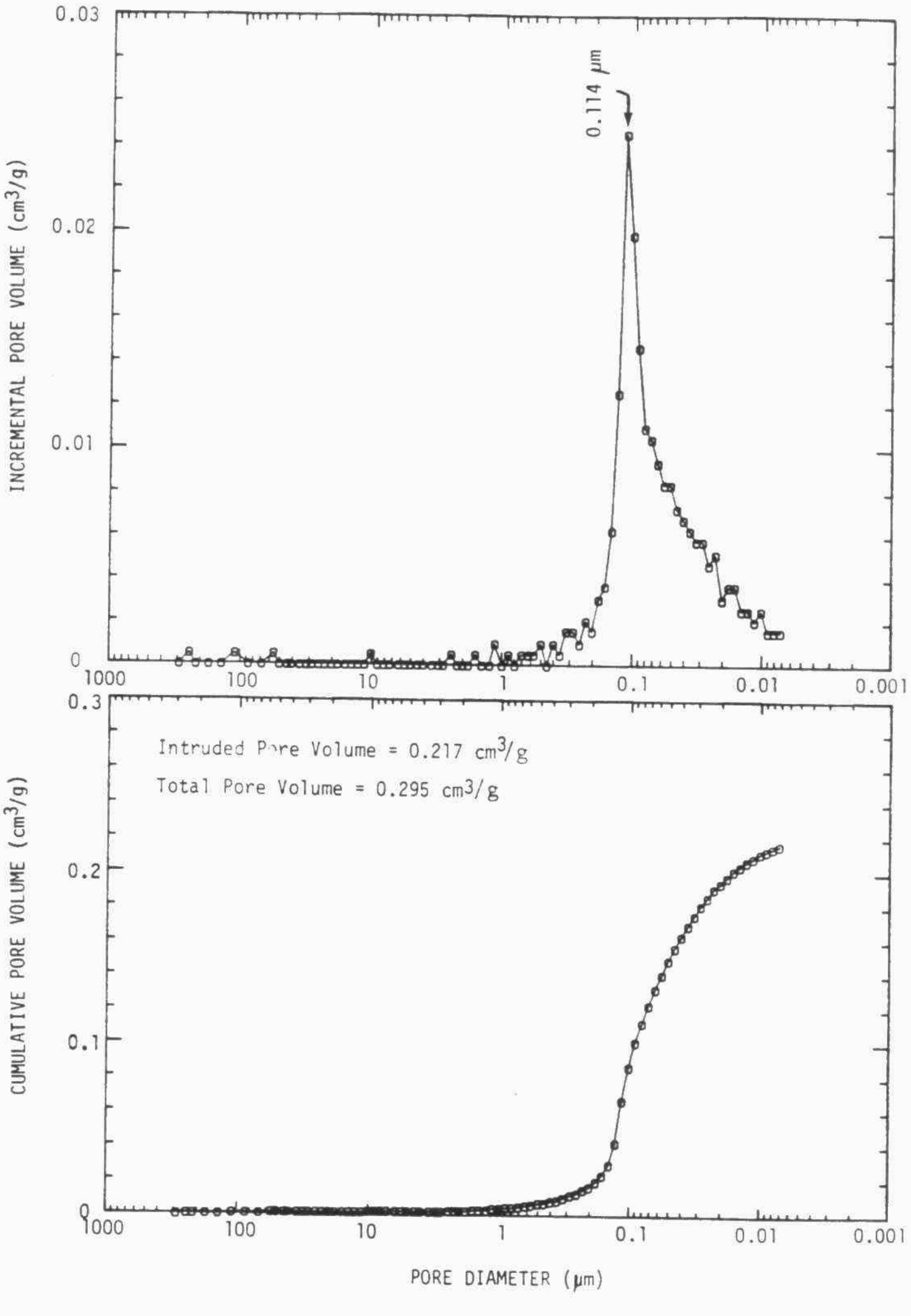

FIGURE J.37 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 40% DIOXANE - 60% LEACHATE

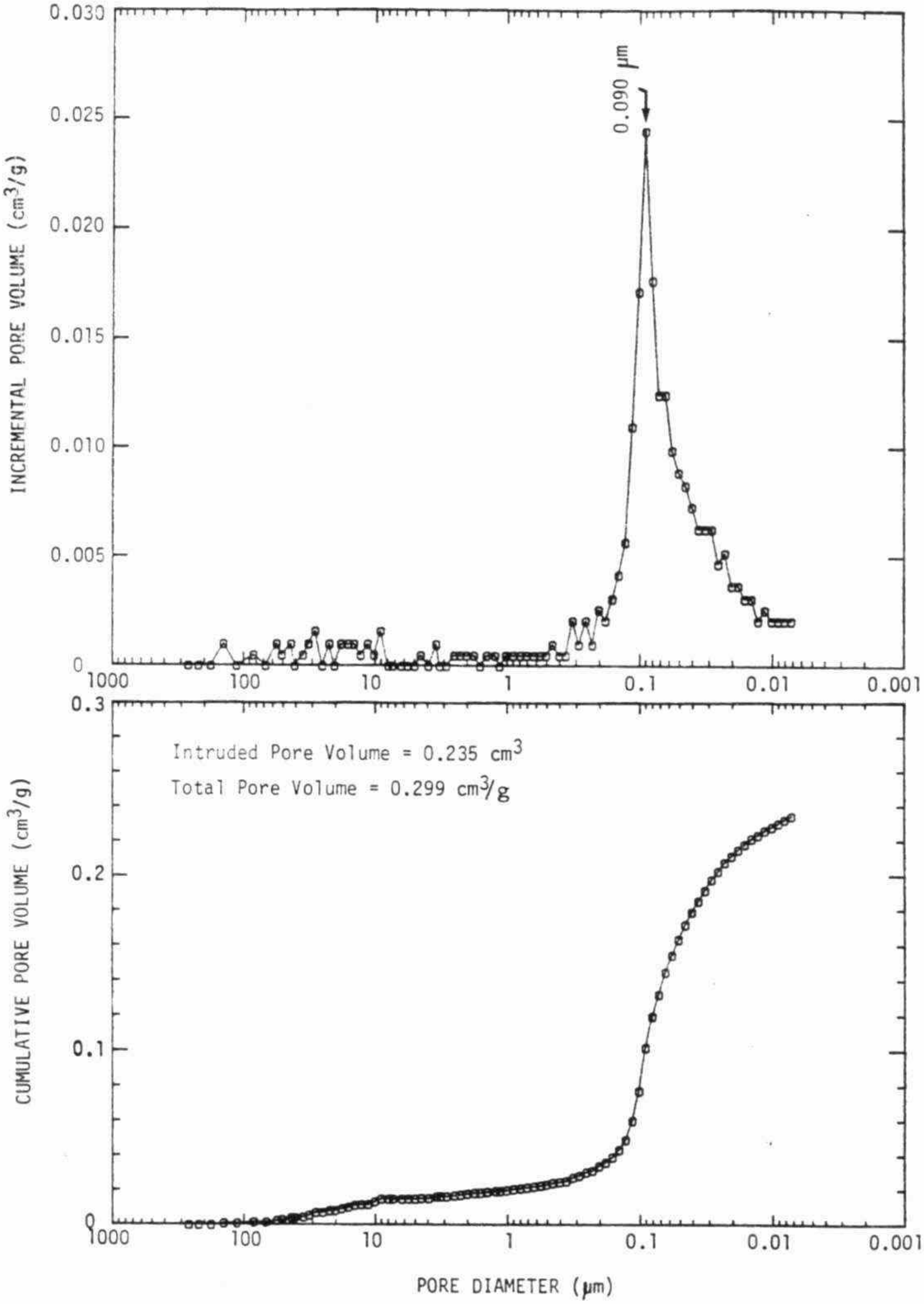

FIGURE J.38 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 70% DIOXANE - 30% LEACHATE

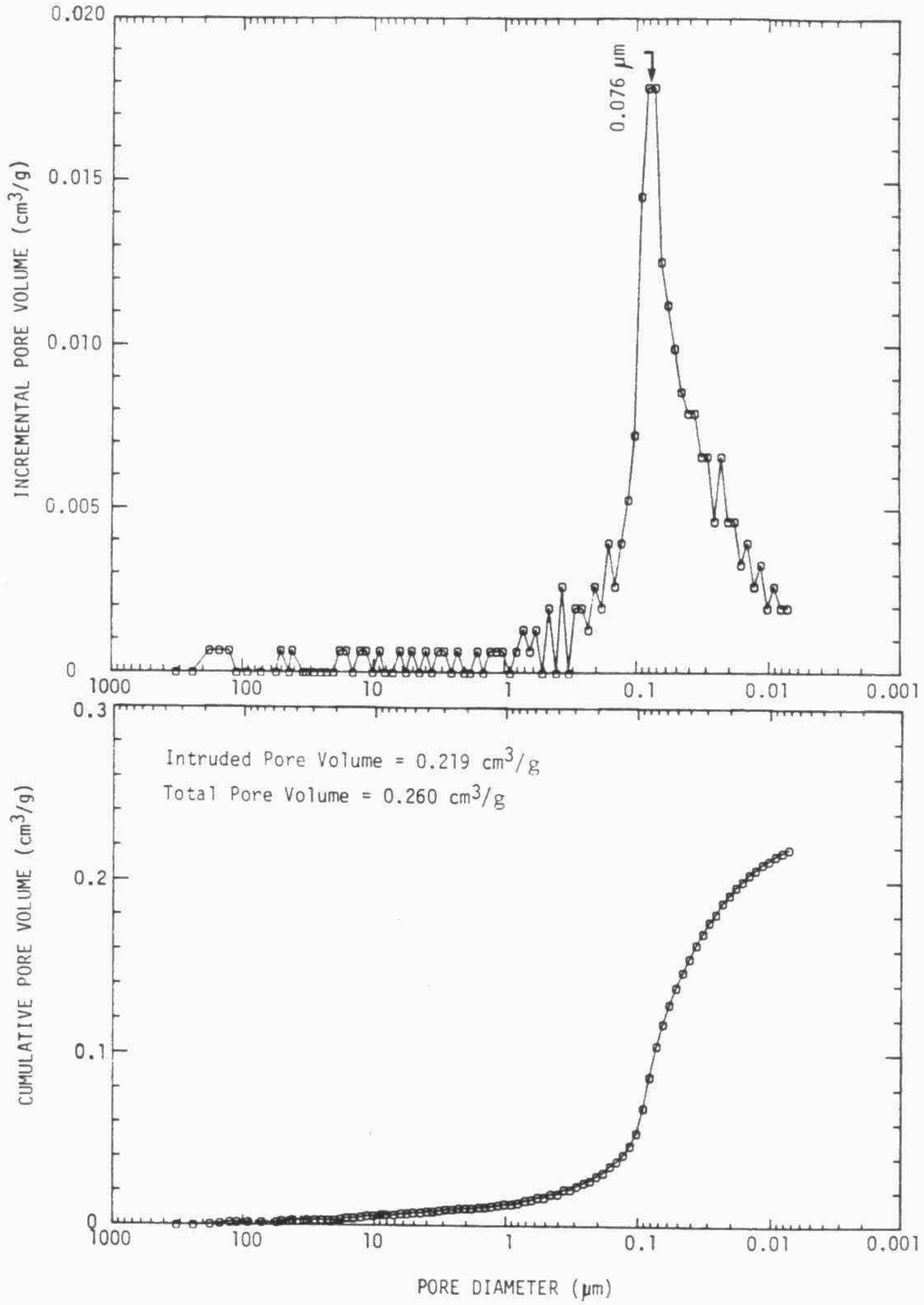

FIGURE J.39 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 100% DIOXANE (σ'_v = 0)

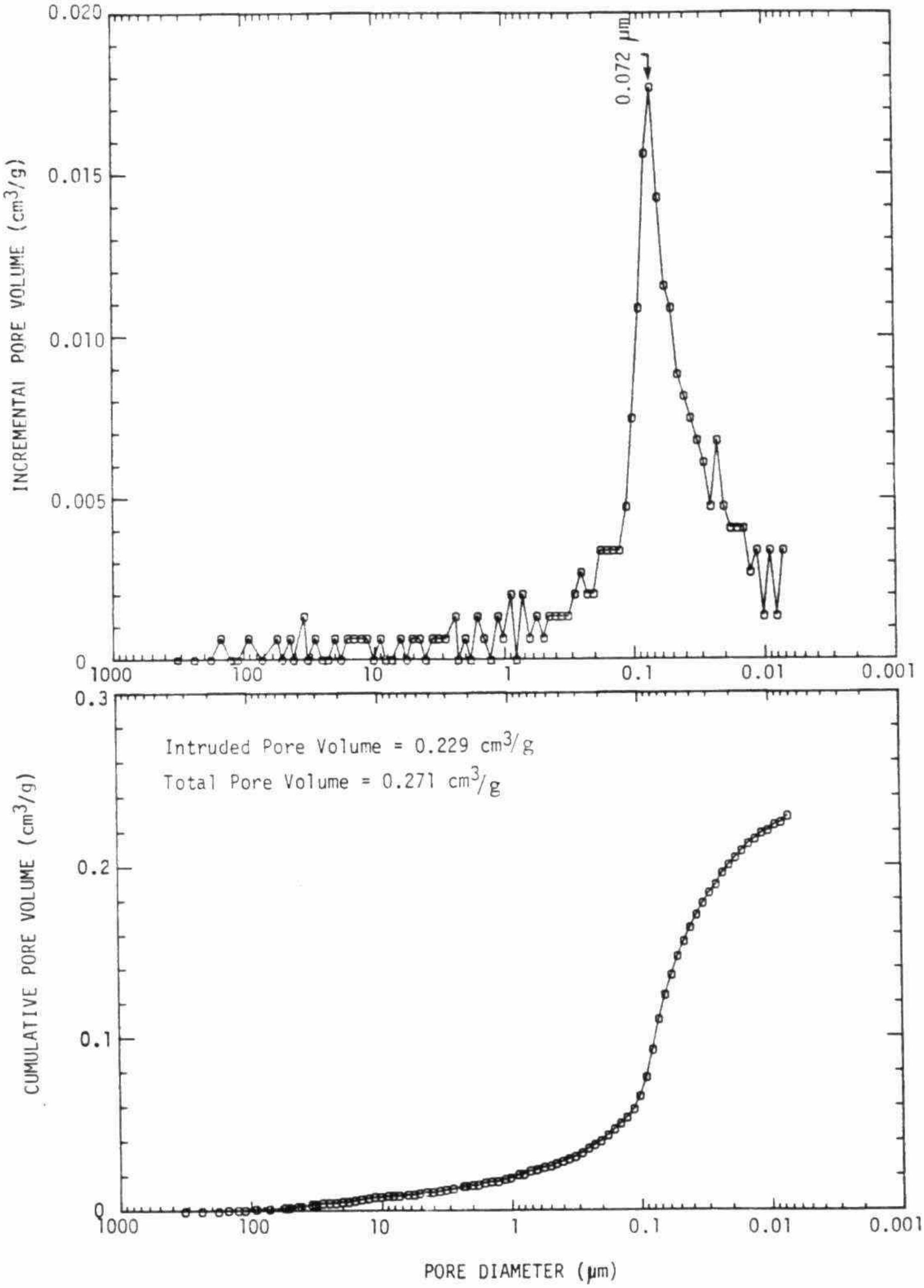

FIGURE J.40 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 100% DIOXANE (σ'_v = 40 kPa)

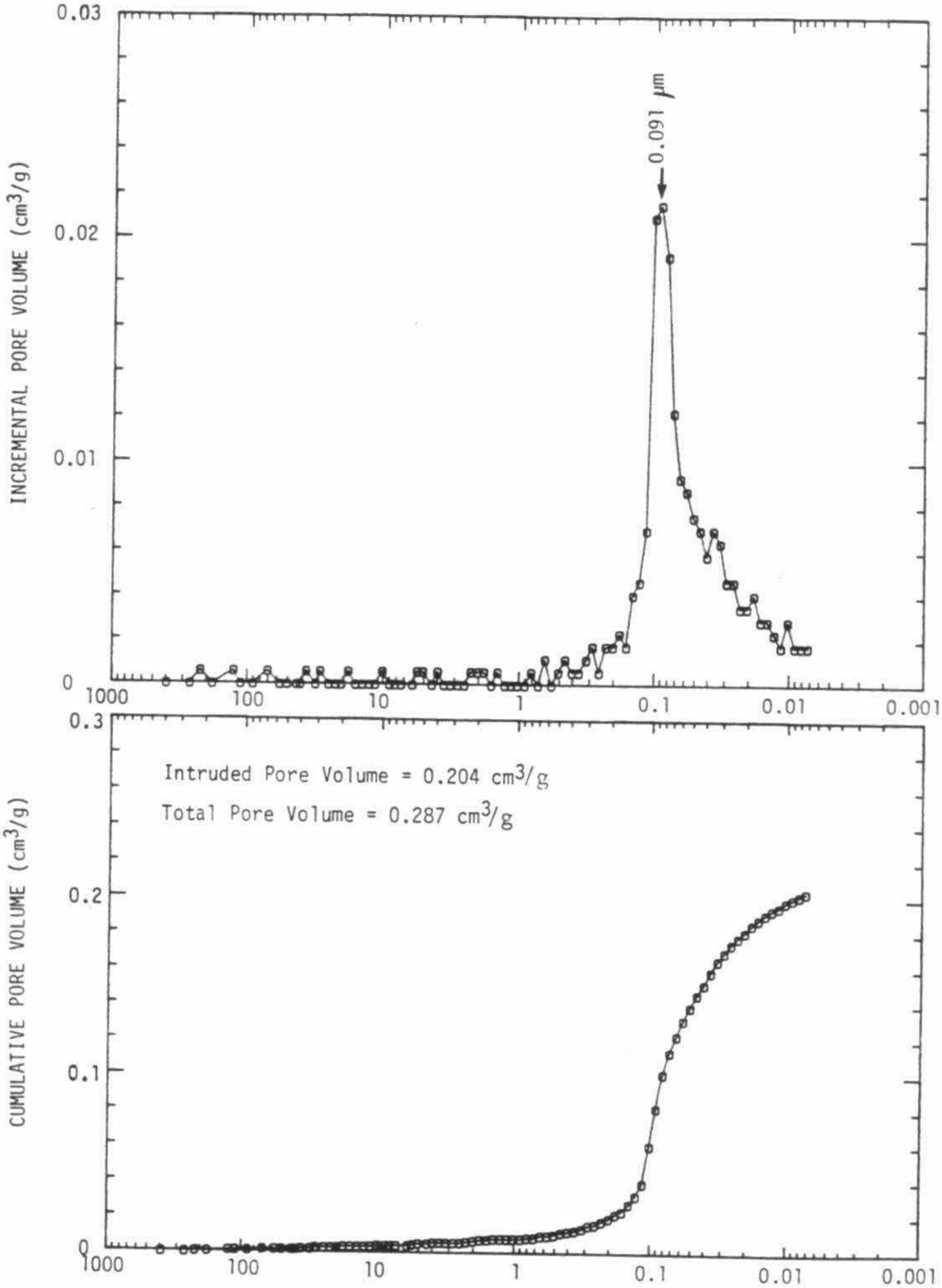

FIGURE J.41 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 40% DIOXANE - 60% LEACHATE (σ'_v = 80 kPa)

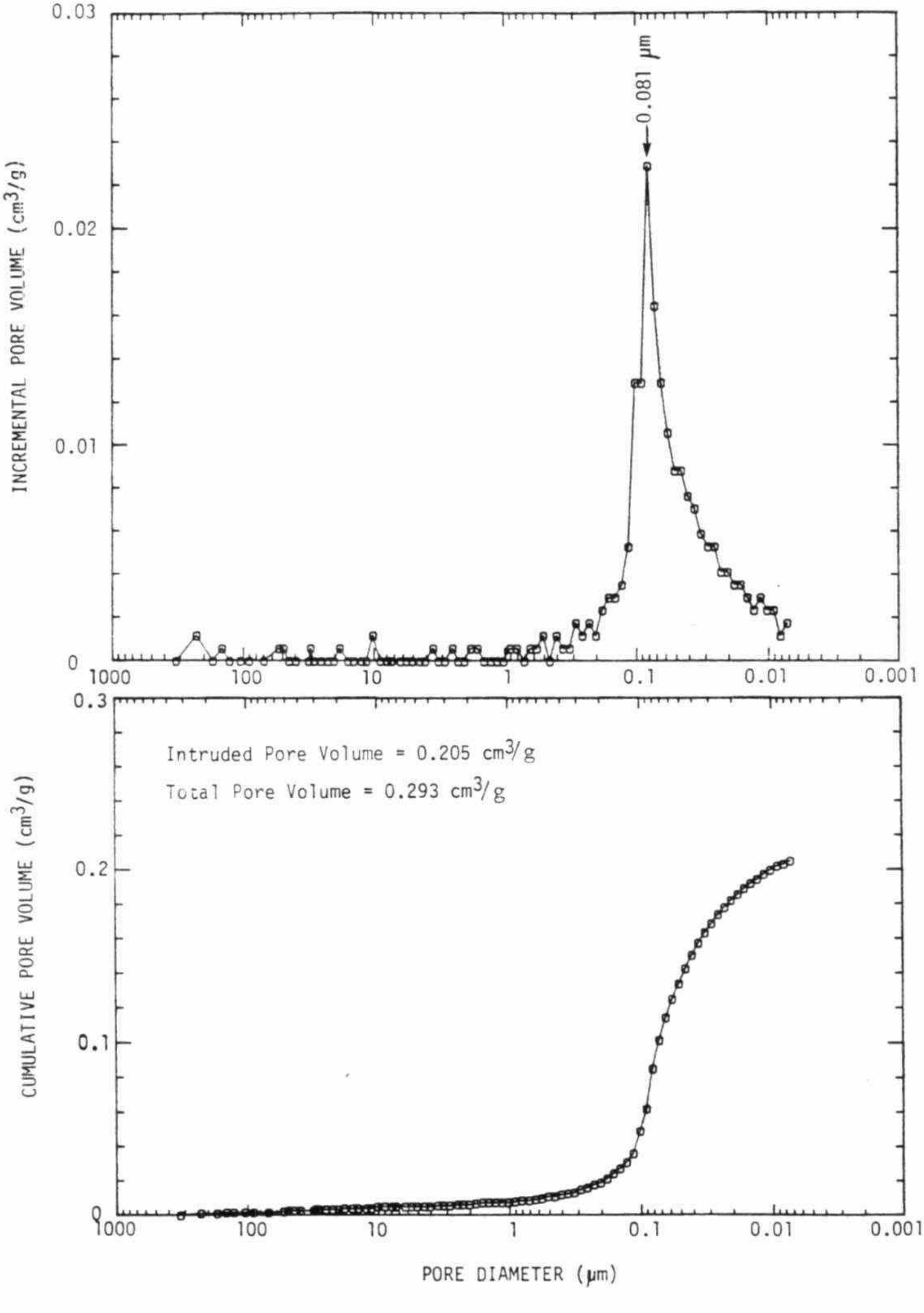

FIGURE J.42 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 80% DIOXANE - 20% LEACHATE (σ'_v = 80 kPa)

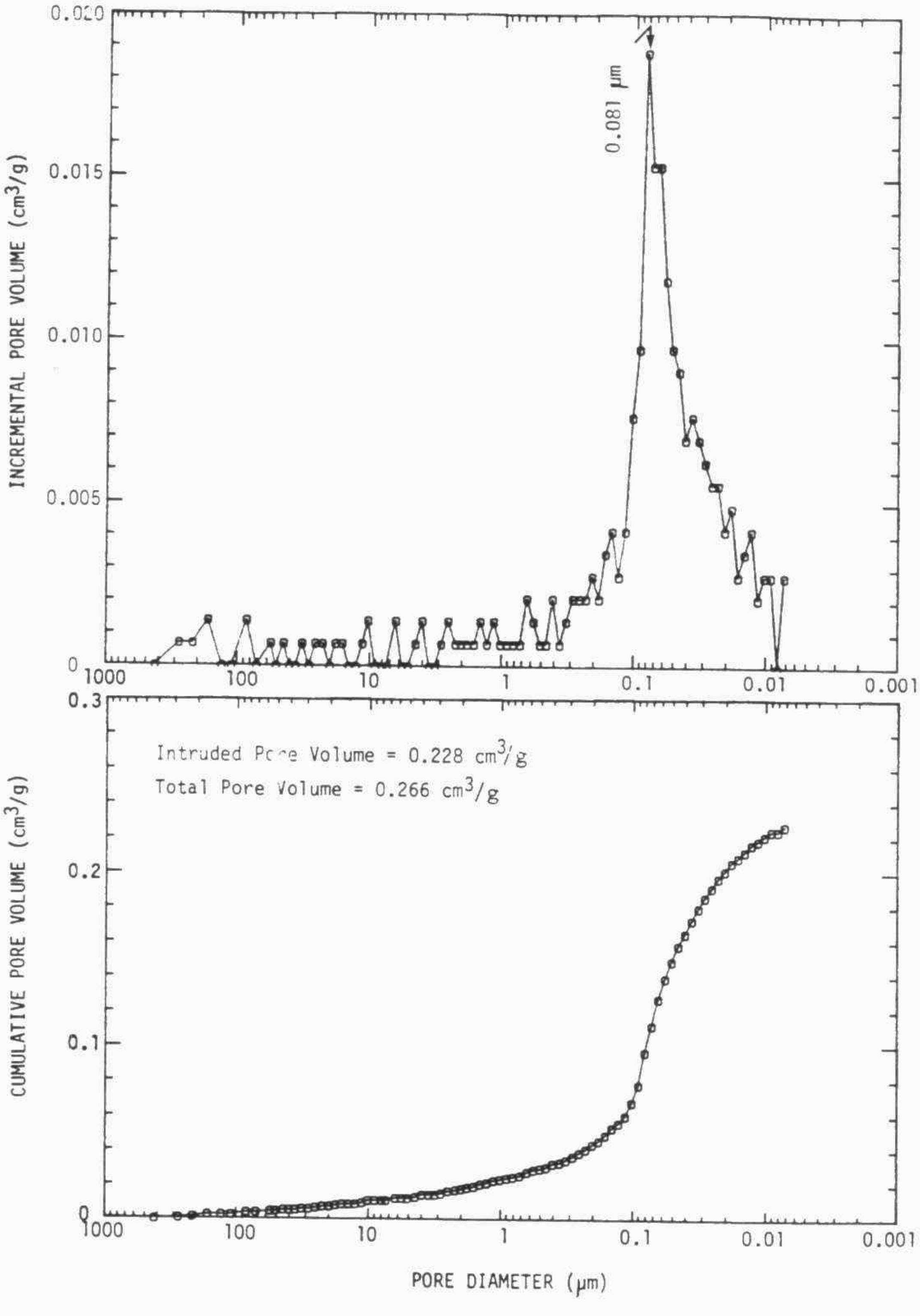

FIGURE J.43 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 100% DIOXANE (σ'_v = 80 kPa)

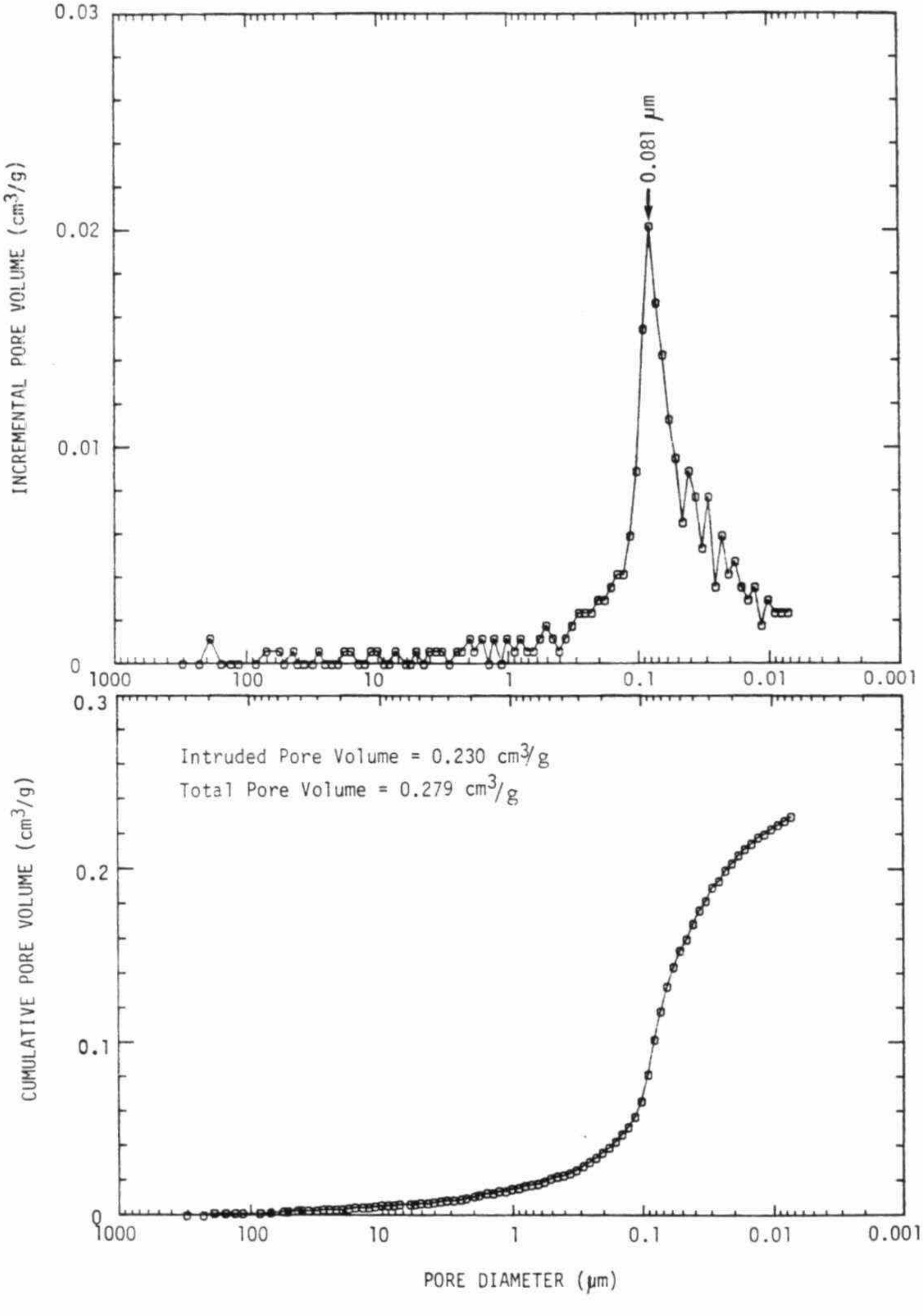

FIGURE J.44 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 100% DIOXANE (σ'_v = 120 kPa)

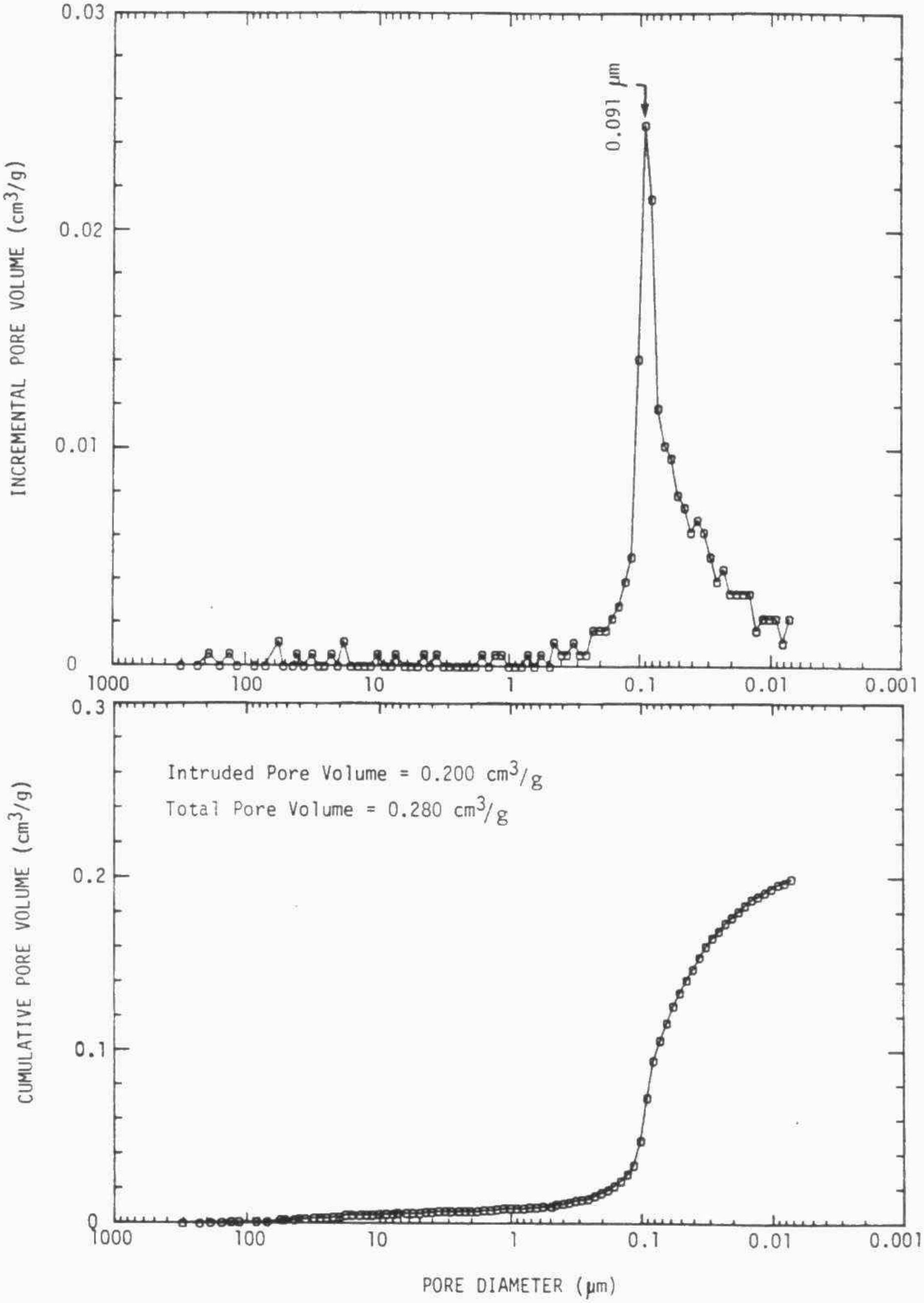

FIGURE J.45 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 40% DIOXANE - 60% LEACHATE (σ'_v = 160 kPa)

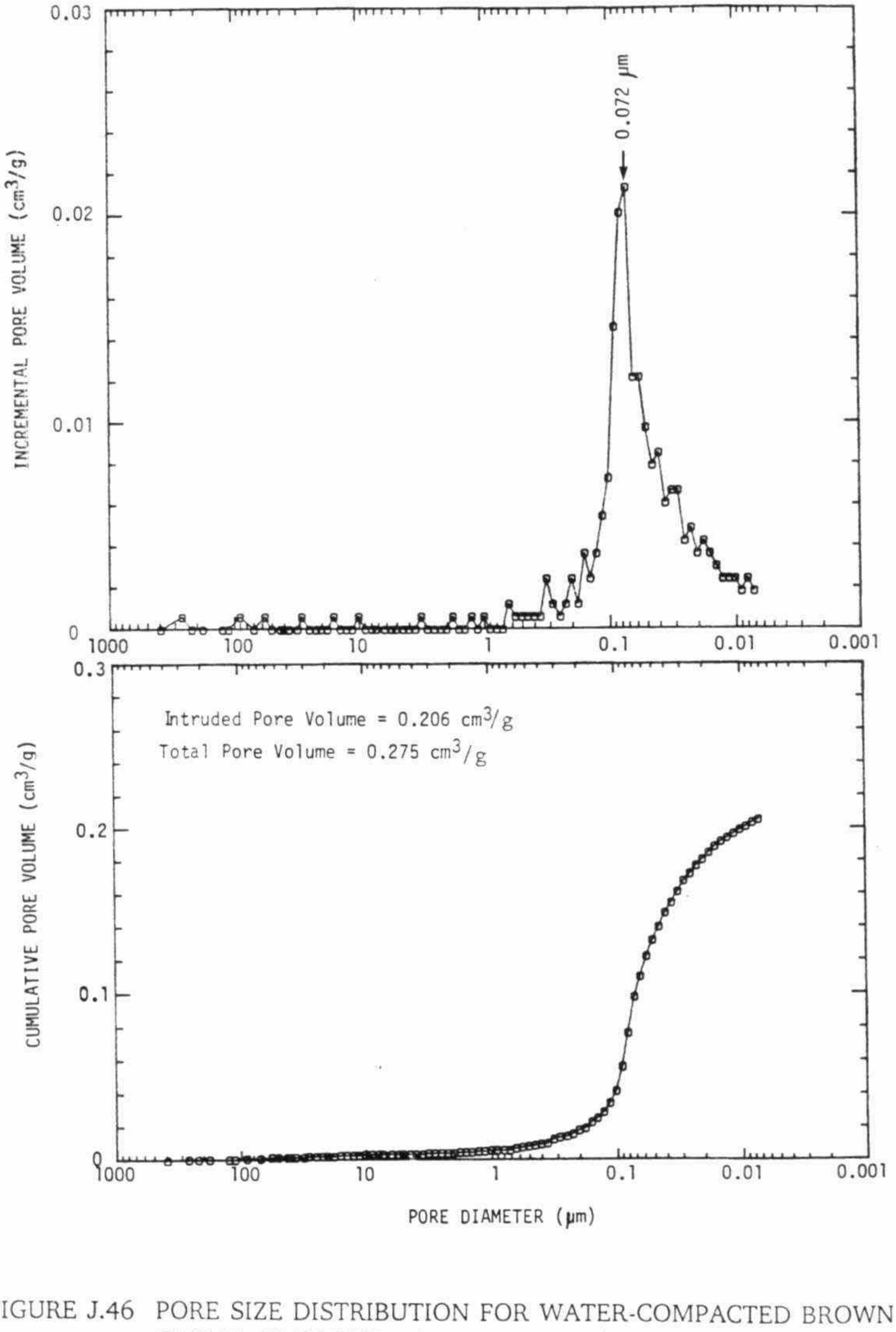

FIGURE J.46 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 80% DIOXANE - 20% LEACHATE (σ'_v = 160 kPa)

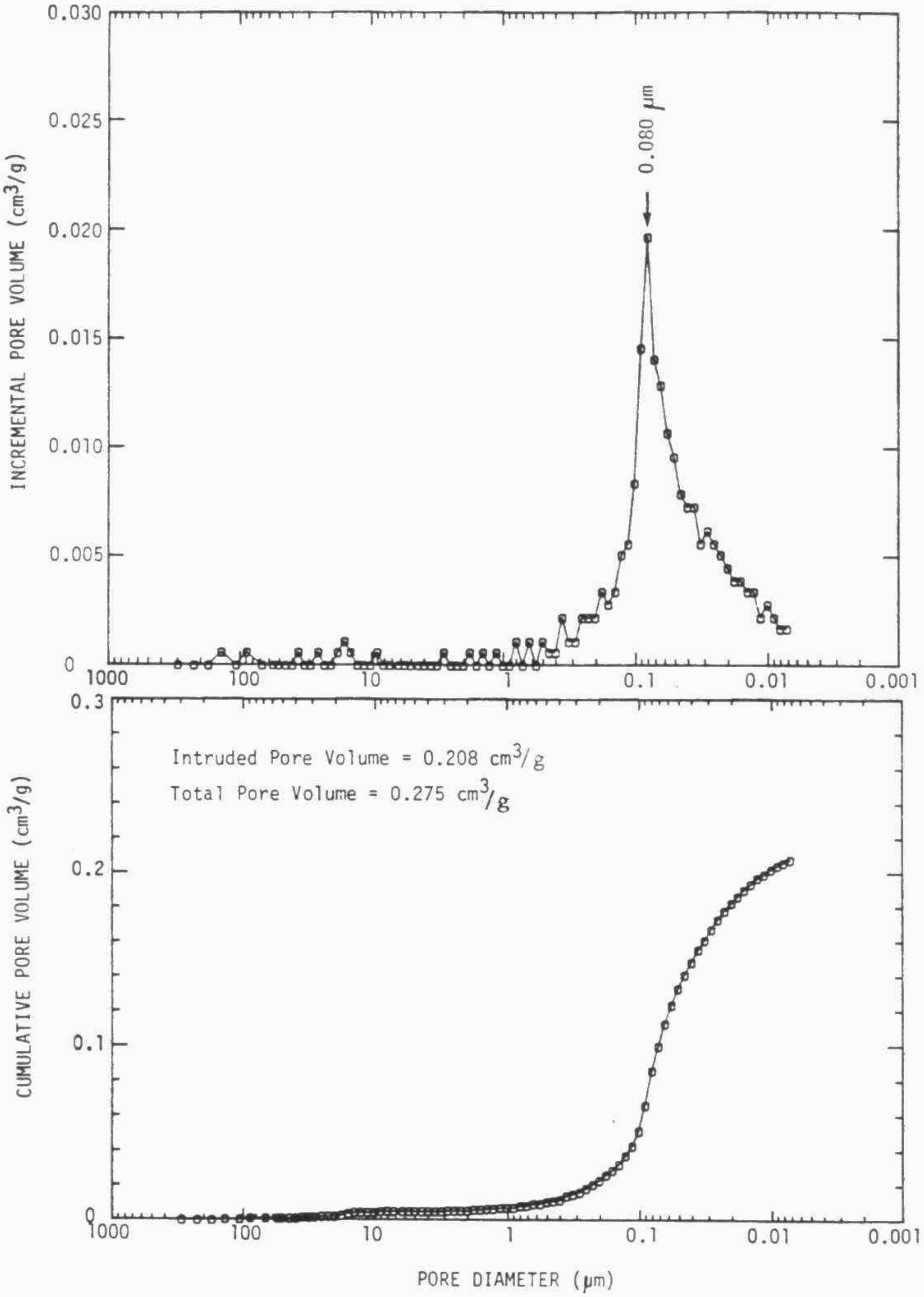

FIGURE J.47 PORE SIZE DISTRIBUTION FOR WATER-COMPACTED BROWN SARNIA CLAY PERMEATED WITH 100% DIOXANE (σ'_v = 160 kPa)

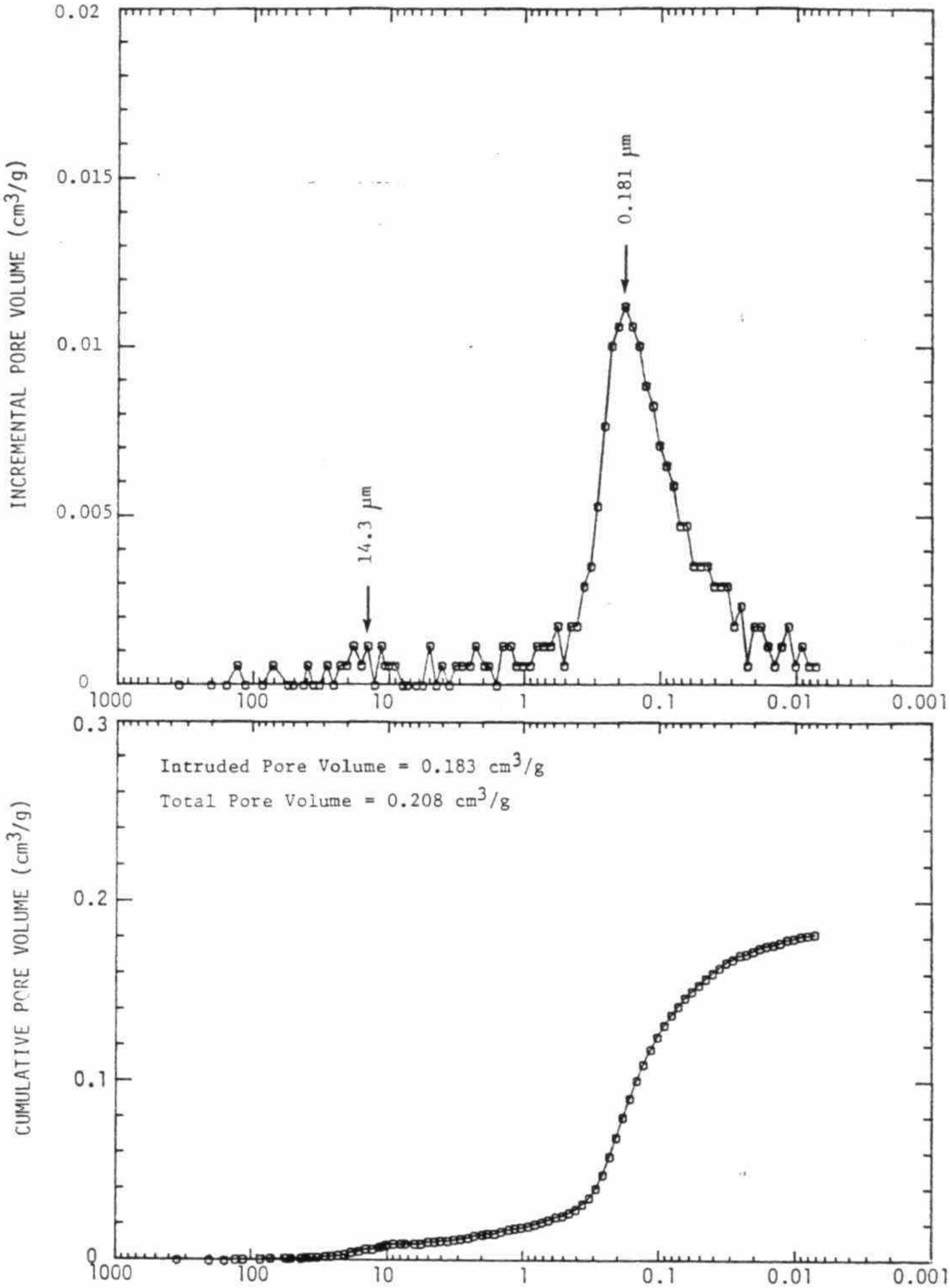

FIGURE J.48 PORE SIZE DISTRIBUTION FOR UNDISTURBED GREY SILTY CLAY (SARNIA) ($\sigma'_v = 0$)

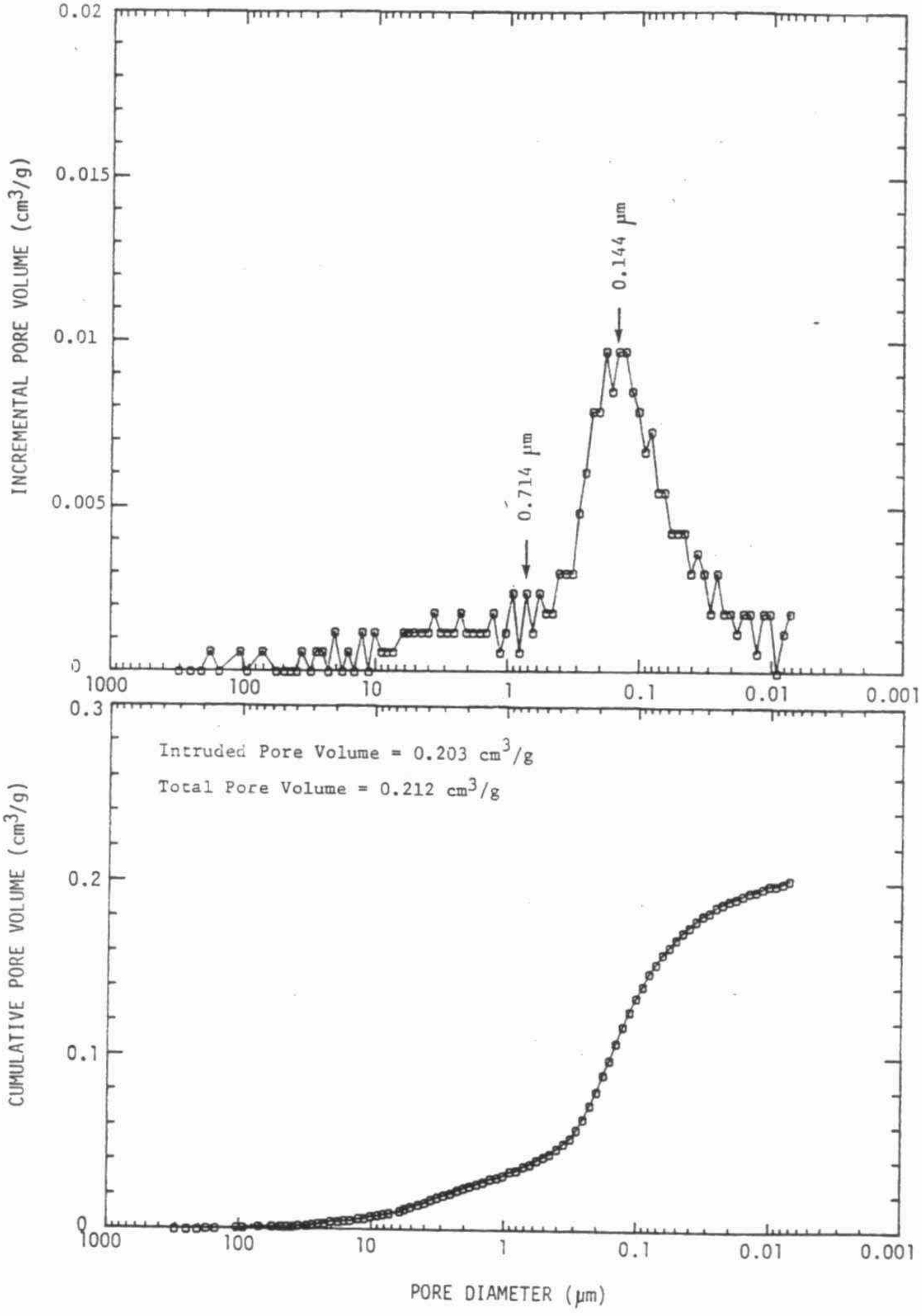

FIGURE J.49 PORE SIZE DISTRIBUTION FOR UNDISTURBED GREY SILTY CLAY (SARNIA) PERMEATED WITH 100% LEACHATE ($\sigma'_v = 0$)

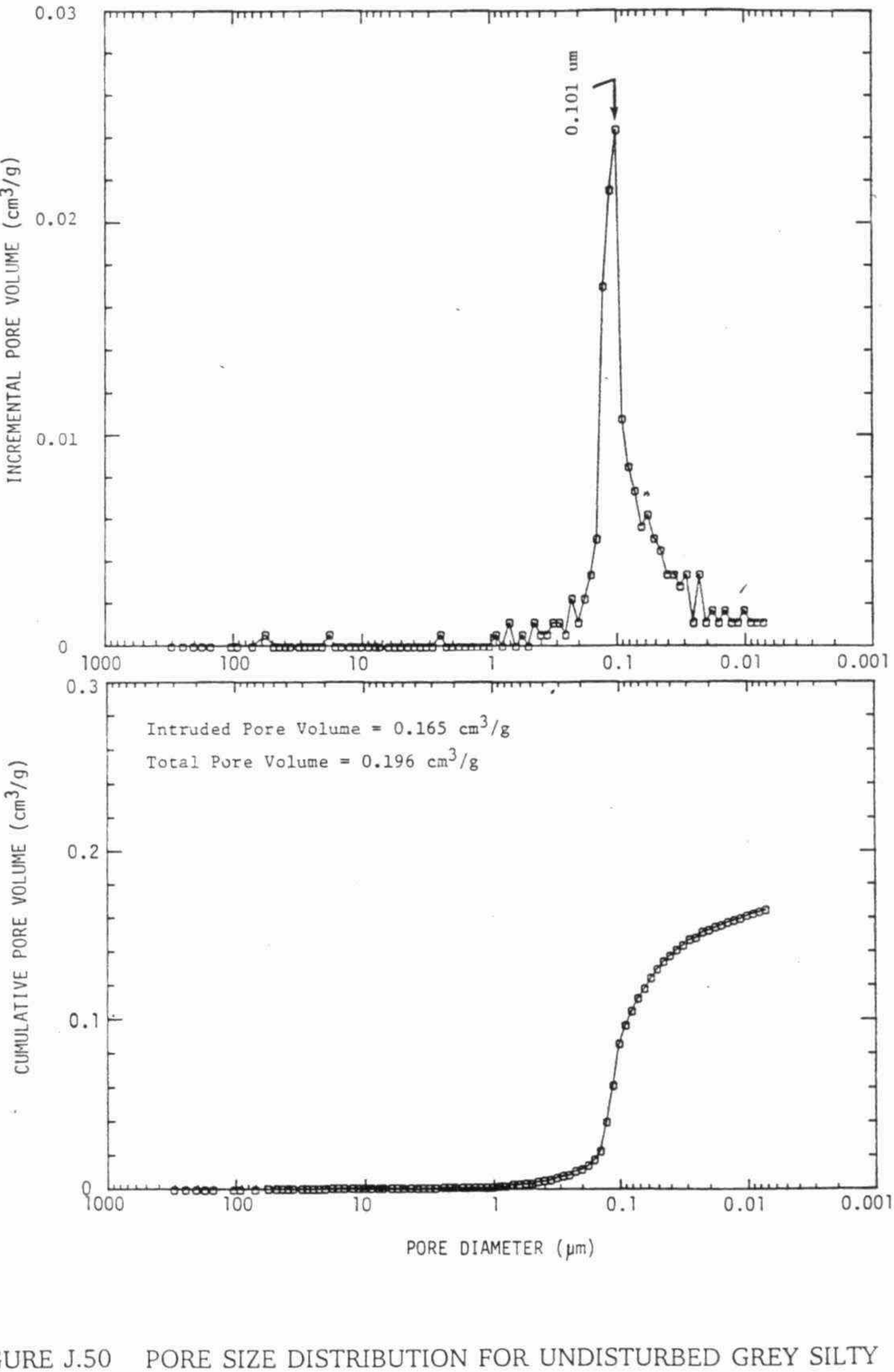

FIGURE J.50 PORE SIZE DISTRIBUTION FOR UNDISTURBED GREY SILTY CLAY (SARNIA) PERMEATED WITH 40% ETHANOL - 60% LEACHATE ($\sigma'_v = 0$)

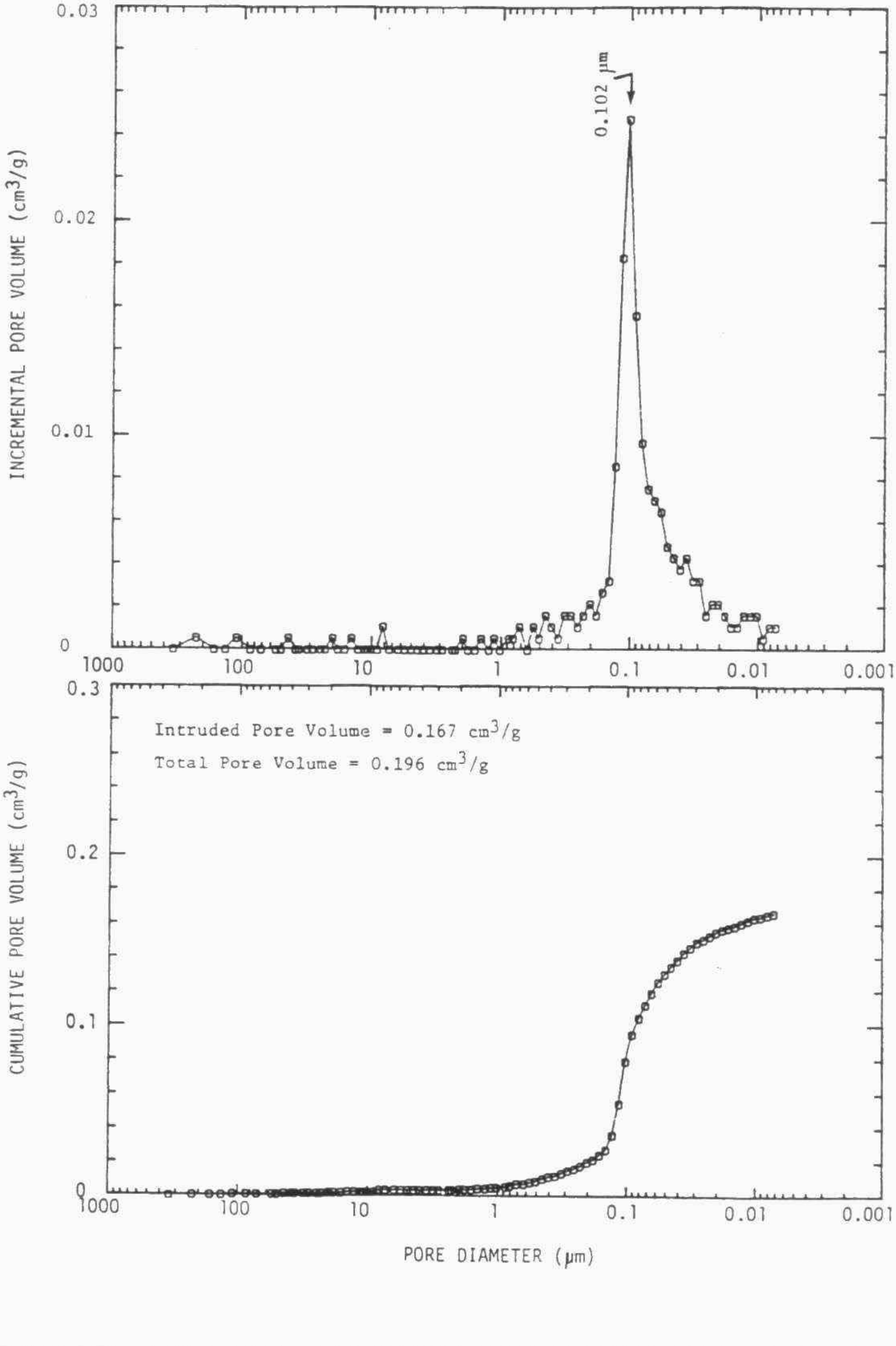

FIGURE J.51 PORE SIZE DISTRIBUTION FOR UNDISTURBED GREY SILTY CLAY (SARNIA) PERMEATED WITH 100% ETHANOL (σ'_v = 0)

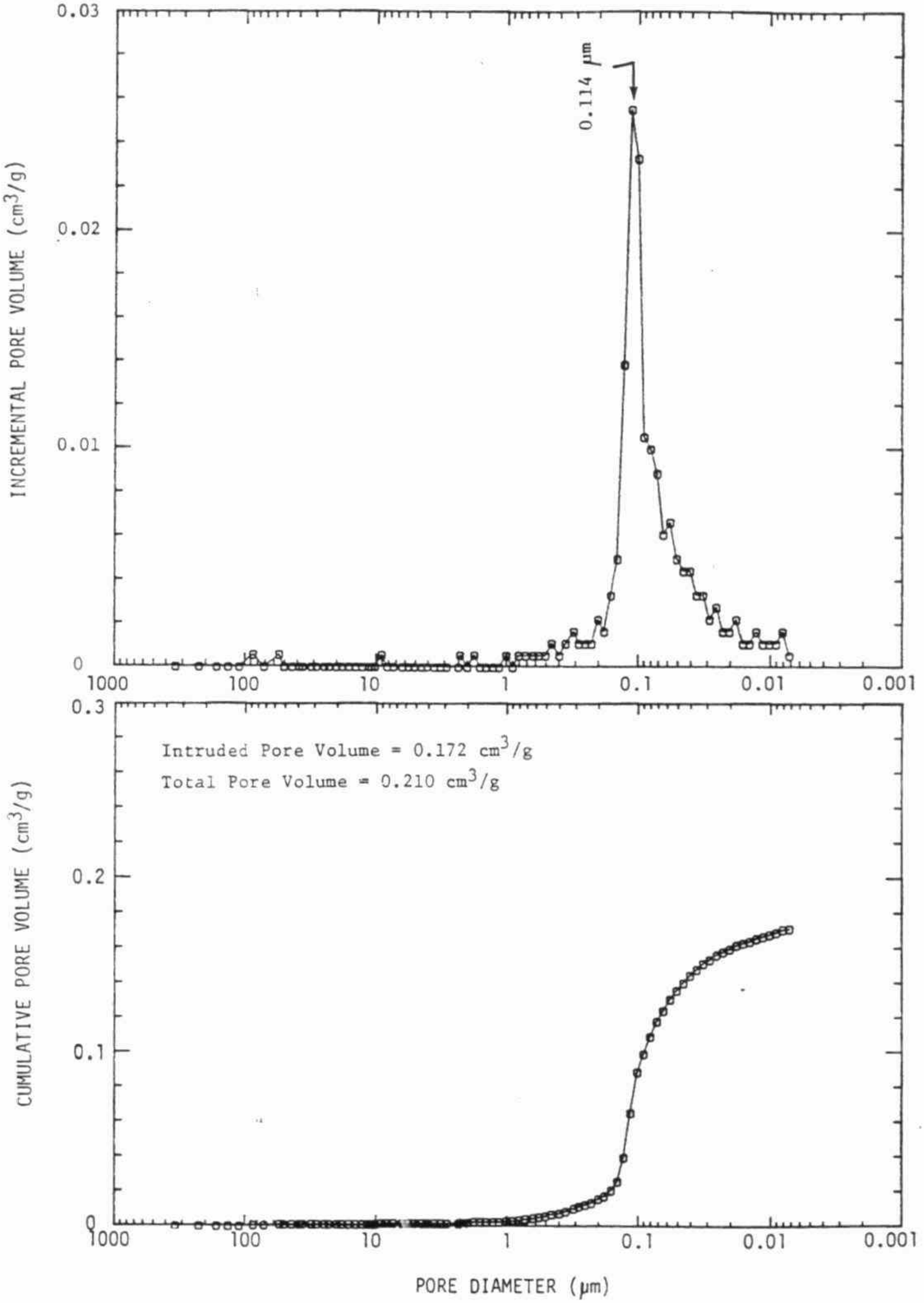

FIGURE J.52 PORE SIZE DISTRIBUTION FOR UNDISTURBED GREY SILTY CLAY (SARNIA) PERMEATED WITH 60% ETHANOL - 40% LEACHATE ($\sigma'_v = 0$)

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